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"International Conference on Recent Progress in Material Science and Mechanical Engineering"
(ICRPMSME 2021)

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About Gandhinagar Institute of Technology

Gandhinagar Institute of Technology was established by Platinum Foundation Trust in December 2006. The Institute is affiliated to Gujarat Technological University and approved by AICTE New Delhi. It is situated near Village “Moti Bhoyan” and 24 km away from Ahmedabad city.

The Trust is registered under Public Trust Act at Ahmedabad, Gujarat. The members of the trust are involved in the social activities and are also promoting the technical interest of the state and country by contributing to the technical institution development.

The vision of the institute is to develop young engineers with active and creative minds. It stresses total development of the students: spiritual, moral, intellectual, social, emotional and physical. The Institute aims to be a leading center for research and engineering study, pursuing knowledge in both fundamental and applied area, and collaborating closely with business and industry in promoting technological innovation and economic development. The institute has team of dynamic and dedicated professors, working hard for overall development of students, so that they get ready for any kind of challenges in their life.

It offers U.G Program in Mechanical Engineering, Computer Engineering, Information Technology, Electronics & Communication Engineering, Electrical Engineering and Civil Engineering. It also offers P.G in Mechanical Engineering with specialization in Thermal Engineering and CAD / CAM and P.G in Software Engineering in Computer Engineering. It also offers MBA Program with specialization in Marketing, Finance, Human Resource, and Information Systems. Gandhinagar Institute of Technology is trying to nurture the intellectual growth of its students and serve humanity through creation, application and dissemination of knowledge relevant to technology and become one of the premier Engineering and Management Institutes and achieve the highest order of excellence in teaching.

Our students are innovative and have excellent acceptability to latest trends and technologies of present time. Our students have also participated in various technical activities as well as sports activities and have achieved various prices at State level and National level.

We have two annual publications, a National level research journal ‘GIT-Journal of Engineering and Technology (ISSN 2249–6157)’ and 'GIT-A Song of Technocrat' (college Annual magazine) and one quarterly publication ‘GIT-Newsletter’. This enhances the documentation culture of the institute. This would definitely create an impact in the minds of readers, by way of providing larger visibility and dimension to the campus. Gandhinagar Institute of Technology proudly celebrated its fifteen years of excellence in Education, but more importantly, taking time to reflect on the past, learn in the moment, and plan for what comes next.

Message from the Director

“The whole of science is nothing more than a refinement of everyday thinking.” – Albert Einstein”

Gandhinagar Institute of Technology started its journey in 2006. The institute started with a vision to develop young engineers with active and creative minds, a sense of understanding and sympathy for others and the courage to act on their beliefs and to treat every student as an individual, to recognize his / her potential and to ensure that he/she receives the best preparation to help one meets his /her career ambitions and goals. GIT is proud to have dynamic and dedicated professors, State of art Laboratory, Wi-Fi enabled campus, Seminar halls, Cafeteria, Open Air Theatre, Amphi Theatre and Centrally air conditioned 3 star rated Resource Centre of Indian Institutes of Technology, Bombay. GIT has a huge lush green campus. A rich library, a tasty canteen, an active sports ground, a soothing Amphi theatre and a spacious open-air theatre makes our institute more vibrant and unique.

The Institute aims to provide a better platform for academic teaching, expert lectures, seminars, interactive sessions, combining all to give the best learning environment. It also provides the students to showcase their involvement outside the classroom by indulging them into various social activities and connects them culturally, socially as well as mentally with the system. The institute with all its glorious achievements and scholastic pursuits created an ideal position for itself in Gujarat. It provides quality education in a highly disciplined environment along with the character building of the students. It gives better opportunities to the students to excel themselves towards the betterme nt of the society. GIT not only gives exposure to academics but also gives importance to overall development of the students and has inserted interpersonal, leadership as well as managerial skills in our students.

It gives me immense pleasure that the fourteenth regular and special edition of our National journal ‘GIT-Journal of Engineering and Technology’ is being published with ISSN 2249 – 6157 for the fourteenth successive year. The annual journal contains peer reviewed technical research papers submitted by the researchers from all domains of engineering and technology. I take this opportunity to thank the esteemed members of Editorial board and Reviewers for being a part of our family. I am sure, with their advice and support; the journal will achieve new milestones in future also. I firmly believe that this current issue Volume-14 will turn out to be Reader’s delight. We are also in process of indexing like Google Scholar, DOAJ, Etc.

We are also happy to share that we have come up with a special edition in the form of post publication of "International Conference on Recent Progress in Material Science and Mechanical Engineering" held at Metallurgical Department, Government Engineering College, Gandhinagar jointly organized with mechanical Engineering Department, Government Engineering College, Patan and sponsored by GUJCOST. The publication highlights some of the latest developments in the areas of material science and other related areas. I feel privileged to make this publication a part of our successive edition.

We are happy to welcome the researchers to contribute in this open access peer reviewed engineering and management journal for the betterment of the society. As the publication gives a broader way of development to academicians and researchers, we wish to have more collaboration with reputed institutes and industries and research organisations across the world. I am thankful to Dr S. P. Dave, Dr H. S. Patel, Dr I. B. Dave, Dr H. N. Panchal and the organizing team to select GIT- JET as a post publication of research performed by the researchers. I also thank all the contributors for their contribution in this special edition.

GIT has been moving towards a huge growth of achievements and progress throughout the span of 15 years and still the journey is continued. In 2020-21, the idea came up with the establishment of **"State Private University".** Expansion of horizons was the necessity of the present era and looking into the same and the need of the hour, it came up with a new vision to embody the spirit of excellence in teaching, research, innovation and creative activities and thus, the institute is in the transformation phase of **"Gandhinagar University"**.

I am very much thankful to Team GIT JET Coordinator for giving proper form to JET regular and the special edition. I congratulate the JET committee who have worked determinedly to conceptualize and compile this publication.

In the end, I give my hearty thanks to the backbone of the institute, our trustees and congratulate all the faculty members, students and parents for their kind support throughout these 15 years and wish to pray that our institution will reach the peak of success, recognition, and glory in near future.

Happy Reading!!!

Dr H N Shah
Chief Editor- GIT JET
Director - GIT

About "ICRPMSME 2021" Conference

"Recent Progress in Material Science and Mechanical Engineering"

The role of Materials and Mechanical Engineering in the country's economy and socio-environmental development is well established. To deepen and broaden knowledge of research trends in the area it is required to bring together experts from academic institutions, industries, research organizations and professional engineers for sharing of knowledge and expertise. This conference associated with recent trends in the field of material science and mechanical engineering. It presents the various research papers on on-going progress and latest development in the conference area. The conference was structured as follows: plenary lectures followed by parallel sessions. The plenary lectures were delivered by eminent personalities of international repute to introduce the theme of the conference. Papers were invited from the prospective authors from industries, academic institutions, R&D organizations and professional engineers. Potential topics to be addressed in this conference include, but are not limited to the following:

- Material Characterization
- Corrosion
- Bio-materials
- Advanced machining processes
- Advanced metal forming, bending, welding & casting techniques
- Composites, Intermetallics
- Advanced materials for different sectors
- Advanced material processing
- Heat Treatment
- CAD/CAM/CAE
- Thermal Engineering
- Nano materials
- Non-destructive Examination
- Powder Metallurgy
- SMART Materials
- Super Alloys

Message from the desk of Chief Patron, ICRPMSME – 2021

સરકારી ઇજનેરી કોલેજ
(ગુજરાત સરકાર)
પશુ જૈવિકની બાજુમાં, સેક્ટર-૨૮, ગાંધીનગર - ૩૮૨૦૨૮.
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Date: 21-05-2021

Message

I am glad that for the first time two departments of two different Government Engineering Colleges, the Department of Metallurgical Engineering, Government engineering college, Gandhinagar and Mechanical engineering, Government engineering college, Patan jointly took the initiative of organizing the GUJCOST sponsored "1st International Conference on Recent Progress in Material Science and Mechanical Engineering (ICRPMSME2021)".

The theme selected "Recent Progress in Material Science and Mechanical Engineering" for the conference is of true significance and relevance that has provided an opportunity to researchers for having an intellectual interaction on various aspects and developments in the area of Metallurgy engineering and Mechanical engineering. This Technical International Conference will provide a prestigious international platform by bringing together local and overseas technical researchers and students to exchange their experienced knowledge and expertise issues relating to the dominating technology trends.

I convey my heartiest congratulations to the convener and other members of the organizing committee for taking steps in the right direction from the beginning that have immensely boosted the morale of participants of this conference. I am confident that the proceedings of this conference will serve as a useful reference point to the researchers for improving and furthering their research studies in the area of Metallurgy and Mechanical engineering.

I would like to convey my greetings to each participant for his/her contributions for the success of this conference.

Dr. Sweta P. Dave
Principal
Government Engineering College, Gandhinagar

Message from the desk of Chief Patron, ICRPMSME – 2021

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Message

As Principal, I take great pride in welcoming all experts and participants of the First International Conference on Recent Progress in Material science and Mechanical Engineering (ICRPMSME-2021) is organized during 28-29 May 2021 jointly by Government Engineering College, Gandhinagar, and Government Engineering College, Patan which received an overwhelming response.

Research activities across the engineering fields pave the way for the industrial world to strive forward with huge advancements. As an educational institution, encouragement and support to research can be provided by establishing a suitable platform for the research community to interact with each other and to share the knowledge. Having this objective, ICRPMSME-2021 was conceived.

ICRPMSME-2021 has been planned to provide the same benefits and learning experience to all the participants. Sessions on different domains, keynote addresses from eminent professionals and professors, and the opportunity to network with the researchers will help the participants immensely in their research careers. This proceeding of the conference has been documented with utmost care. I believe firmly that this will stand as a great source of knowledge and researchers.

We are looking forward to excellent interactions with great experts from different countries worldwide and sharing new and exciting ideas and outcomes.

My sincere thanks and appreciations are due to the Organising team of both colleges for making great efforts in organizing ICRPMSME 2021 and making it a grand success.

Date: 17/05/2021

Dr.H.S.Patel
Principal

Message from the desk of Convener & Organizing Secretary ICRPMSME – 2021

Dear Academicians and Researchers,

It is our humble privilege and honor to welcome you all to the GUJCOST sponsored “1st International Conference on Recent Progress in Material science and Mechanical Engineering. (ICRPMSME2021)” jointly organized by the Metallurgy Engineering Department, Government Engineering College, Gandhinagar and Mechanical Engineering Department, Government Engineering College, Patan, during the 28th to 29th May 2021.

This conference aims to give a platform to researchers to share their results and reviews and know the present technological developments in this fast-moving Information Era. We will also facilitate the participants to expose and share various novel ideas to bridge the researcher community working in academia and other professionals through research presentations and keynote addresses on recent technological trends in the field of Material science and Mechanical Engineering. This conference will also helpful for PhD research scholars to present their research. The major keystone has been the keynote sessions and discussions at the conference, which will widen your knowledge and network. We believes that it will be an absolutely great opportunity for you to gain the academic and research insights.

We thank in advance the GUJCOST for their funding, conference committees for extending their valuable time in organizing the program and all the speakers, authors, reviewers, session chairman/ coordinators, other contributors from all over the world for their hard work and their trust in the excellence of “ICRPMSME2021”.

We cordially invite all the enthusiasts to participate with full in ICRPMSME2021, giving huge exposure and global opportunities to all.

Dr. I B Dave
Convener

Dr. Daulat Kumar Sharma
Organizing Secretary

Message from the desk of Convener, ICRPMSME - 2021

Dear Professors and Researchers,

It is my privilege and honor to welcome you all to the GUJCOST sponsored "1st International Conference on Recent Progress in Material science and Mechanical Engineering. (ICRPMSME2021)" jointly organized by the Government engineering college Gandhinagar and Government engineering college, Patan, during the 28th to 29th May.

The main goal of organizing this conference is to share and enhance the knowledge of every individual in this fast-moving Information Era. We have given an excellent opportunity to those who thirst to know the present technological developments and share their ideas. This conference will also facilitate the participants to expose and share various novel ideas. The conference aims to bridge the researchers working in academia and other professionals through research presentations and keynote addresses on current technological trends in the field of Mechanical and Material science. The major cornerstone has been the number of key persons/researchers present for keynotes and discussions at the conference. You will get ample opportunities to widen your knowledge and network.

I want to thank in advance the conference committee for extending their valuable time in organizing the program and all the authors, reviewers, and other contributors for their sparkling efforts and their belief in the excellence of "ICRPMSME2021".

I cordially invite all the enthusiasts to participate with full vigor in this celebrated event, giving immense exposure and global opportunities to all.

Dr. Hitesh N. Panchal

Convener

Conference Patron

Dr. S. P. Dave
Principal, GEC-Gandhinagar, India

Dr. H. S. Patel
Principal, GEC-Patan, India

Conference Convener

Dr. I. B. Dave
Professor, GEC-Gandhinagar, India

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A Review on Effect of Alloying Element on Aluminium Anode

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Abstract

Aluminium is most widely used as a structural material world wide because of its unique properties and ability to alloy with other elements. These elements improve desirable mechanical properties and remarkably affect the chemical properties by changing the microstructure of Aluminium from homogeneous solid solution to complex structure with multiple intermetallic phases. This will change the corrosion resistance of pure aluminium as it belongs to a group of passive metals. Aluminium is the most preferable metal for sacrificial anode for cathodic protection techniques because of its lightweight, high anode efficiency and current capacity. Pure and unalloyed Aluminium is not suitable for a sacrificial anode due to the development of the protective layer on its surface this will restrict direct contact of Aluminium with the Environment. The Reactivity of Aluminium can be changed from passive to active by adding other elements. Chemical composition is the primary parameter that governs the passivity and corrosion resistance of metals. This article deals with the overview of the role of alloy chemistry and important aspects like a breakdown of passive film and formation of an intermetallic compound that will affect the behaviour of Sacrificial Aluminium Anode.

Keywords: Aluminium alloy, Sacrificial anode, Passivity, Electrochemical Behaviour.

1. Introduction

Metal degradation or corrosion is one of the far reaching challenges in the industrial world. It is nothing but the reaction of metal with its service Environment and this will lead to the deterioration of valuable service properties of the metal. Several techniques have been developed to prevent corrosion like inhibitors, design modification, coating and anodic-cathodic protection from which Cathodic protection (C.P.) being deployed by major industries.[1-3] Cathodic Protection is nothing but reduce or restrict the corrosion by making the metallic structure as a cathode in corrosion cell. There are two cathodic protection methods that impressed current method and sacrificial anode method respectively. Out of these two methods sacrificial anode method is most probably used for preventing oil pipelines, marine structure and some domestic structures. This is most widely accepted due to several benefits like ease of installation, no need for an external power source, and also suitable for localized protection. Main objective of this method is that the metallic structure to be protected is coupled with more active metal (anodic metal) and makes it cathode. Hence, all the corrosion concentrated at active metals called a sacrificial anode. This is brought off by altering the electrode potential of the metallic structure so that it can be placed in the immunity region, therefore further corrosion is not allowed [2,4].

Nowadays, Magnesium (Mg), Zinc (Zn) and Aluminium (Al) are most preferable sacrificial metals for cathodic protection. From which, Aluminium is acquire appreciable properties as the sacrificial metal like light in weight and density, ease of availability, large electrochemical equivalent, thermal and electrical conductivity, high current capacity, and reasonable cost.[5]

2. Passivity of Aluminium

Passivity is nothing but loss of chemical reactivity. Some active metal in a certain environment reacts with the environment and forms a layer of corrosive product on its exposed surface; this product may be oxide, sulphide, and hydroxide; this layer acts as a barrier for the direct contact of metal to the environment further reduces the reactivity of metals. In such a way Aluminium is also covered with an oxide layer when aluminium comes in contact with atmospheric oxygen, whether in solid or liquid form.[6]

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The existence of this film was first reported by Joseph W Richards in 1896. There is just about the immediate formation of an oxide film having the general formula $Al_2O_3.nH_2O$ as given by the reaction a, b and c respectively, which is few nanometres thick and this film isolates the aluminium from direct contact with the environment. [7, 8]

Table1. Comparison between sacrificial anode materials [3]

Properties	Aluminium	Zinc	Magnesium
Density (gm/cc)	2.70	7.13	1.74
Open circuit potential (SHE)	-1.66	-0.76	-2.38
Anode capacity (amp.hr/kg)	2500	780	1251
Consumption rate (kg/amp.yr)	3.4	11.5	7
Environment	Seawater Freshwater Backish water High and low resistive medium	Low resistive medium	High resistive medium Subsoil Freshwater

[a] Oxidation:

$Al \rightarrow Al^{+3} + 3e^-$

[b] Reduction:

$2H^+ \rightarrow 2e^- + 2H_2$ (Hydrogen reduction)

$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ (in alkaline or neutral media)

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ (in acidic media)

[c] Passivation:

$2Al^{+3} + 3O^{-2} \rightarrow Al_2\ O_3$

This passivating behaviour of aluminium is subject to the stability of oxide film and this is express by their Pourbaix diagrams which give idea about the thermodynamic oxidizing and reducing power of the major stable oxides, hydroxides, and oxyhydroxides of a various chemical compound. If we talk about aluminium oxide then it is a very stable oxide and also Rpb (Pilling-Bedworth ratio) for this oxide is 1.28 which concludes that this oxide film is denser than metal. This property of oxide film is enough for protecting the aluminium from further corrosion that's why aluminium has great atmospheric corrosion resistance. The parameter that affects the development of oxide is oxygen pressure, temperature, the surface of the metal and chemical substances present in the metal.[9,10]

3 Depassivation of Aluminium

Pure and unalloyed aluminium cannot be used as the sacrificial anode because of the passive behaviour of aluminium as we discussed in the above paragraph. The breakdown of this passive film (Al_2O_3) improves the performance of the sacrificial aluminium anode. [1,2] Breaking or weakening of the passive film moves the aluminium surface from the naturally passive state to the active state. Methods for this adjustment of aluminium surface by applying cathodic current, or by addition of alloying elements at a low quantity having a suitable negative potential which encourages depassivation and shifts the operating potential of the aluminium to the more electronegative direction. [11-12]

In 1966, Reading and Newport carried out study to understand event of the addition of different metals on the performance of aluminium sacrificial anodes in seawater and found that many metals which improve the efficiency of the anode by forming intermetallic and other second phase particle depends on solubility limit of the solvent metal in Aluminium matrix (Table 2) and make more active aluminium electrode potentials. Generally, alloying elements are added into Aluminium are term as depassivators and modifiers. [8,13]

Table 2 Solubility of the elements in aluminium [14]

Alloying element	Temp (°C)	Solid solubility(wt%)	Liquid solubility(wt%)	Type of system
Zn	**380**	**82.8**	**95.0**	**Eutectic**
Mg	**450**	**14.9**	**35.0**	**-**
Cu	**550**	**5.67**	**33.15**	**Peritectic**
Si	**580**	**1.65**	**12.16**	**-**
Sn	**230**	**<0.01**	**99.5**	**Eutectic**
Ti	**665**	**1.0**	**0.15**	**Peritectic**
Zr	**660**	**0.28**	**0.11**	**Peritectic**
Pb	**660**	**0.15**	**1.52**	**-**
Ga	**30**	**20**	**98.9**	**-**
Bi	**660**	**0.87**	**<0.1**	**Monotectic**

Addition of alloy metal and impurities present in aluminium can pay-off degradation in passivating properties and it is basically governed by the nature and distribution of intermetallics compounds, the shape and particle size of the intermetallics. Beginning with the physical metallurgy of Al alloys clearly shows that all the alloying elements have negligible solubility at room temp and the addition of elements beyond this limit will give rise to the formation of another solid solution or compound. These compounds may be binary, ternary or even quaternary depending on the chemistry of the developed alloy. However, an alloying element can also form compounds with or without aluminium. This is possible in the system of Mg and Zn they will produce Mg_2Si and $MgZn_2$ in the 6XXX and 7XXX series respectively. These intermetallics compounds form in the liquid state by eutectic and peritectic reaction or in the solid state by precipitation process during the cooling or heat-treatment process.[15-16]

These intermetallics compounds take part in the galvanic corrosion process of the alloy, which may be anodic or cathodic to the aluminium matrix depending on their open circuit potential as listed in table 3. Therefore, this brings out development of galvanic corrosion cells between intermetallics and aluminium matrix and result is dealloying or localized corrosion. The Driving force for localized corrosion is the potential difference between intermetallics and aluminium matrix. These intermetallics lead to generalized surface corrosion like pitting; this will be initiated by an oxygen-reduction process on cathodic intermetallics. Pitting is usually starting when the oxide layer is breaking and it is the origin of localized corrosion.[16-17]

The intermetallics may be Age-hardening precipitates, in the ageing process, the usual sequence is the formation of supersaturated solid solution (SSSS)-GP zones-metastable phases- stable phases. In GP zones [Guinier-preston zone], decomposition of SSSS of Al is producing precipitates (ppts) that may be fine or coarse. fine ppts distributed throughout the matrix and coarse ppts concentrated on grain boundaries, and intergranular corrosion and stress corrosion will be initiated. The coarsening of ppts restricts the growth of the protective oxide layer and breaking in the oxide layer initiates corrosion. As suggested by several theories, at the breaking point where is no oxide layer is present from that area pitting corrosion is started in presence of chlorides which leads to Al dissolution [17-18]

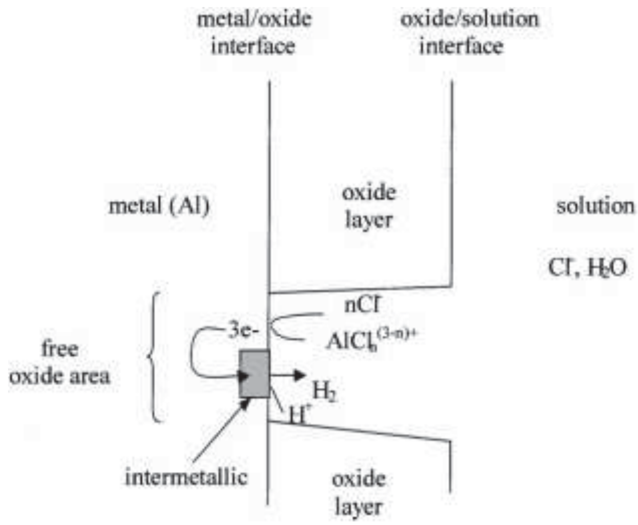

Fig 1 Formation of pit in oxide free area [7]

Table 3 open circuit potential of intermetallic compounds (NaCl, H_2O_2 solution, ASTM G 69)[16]

Position	Intermetallic Compound	Open Circuit Potential (mV SCE)
Anodic	Cu	-110
	Si	-170
	Al_3Fe	-470
	Al_2Cu	-640
	1050A	**-750**
Cathodic	Al_6Mn	-760
	$MgZn_2$	-960
	Al_3Mg_2	-1150
	Mg_2Si	-1200

4. Effect of Chemical Composition

Various research studies suggest that alloying addition has the strongest effect on the aluminium anode. Here, we summarized some of their research papers mainly focusing on the effect of alloying elements addition for improving dissolution of alpha α aluminium matrix in the binary compound of Al-X (X-Zn, Mg, Fe, Sn, Ti etc) and Ternary compound of Al-X-Y (X, Y is Zn, Mg, Fe, Sn, Ti etc).

4.1 Effect of Zinc

Zinc is a major alloy in the 7XXX series, which is heat treatable and has the highest strength from the other Aluminium alloy. [19] Zn has the greatest solid solubility in the aluminium matrix which is 66.4 atomic weight percentage and Zn makeup a eutectic type of system with aluminium, in which liquid aluminium give α solid solution of Aluminum and Aluminum rich intermetallic phase [20].

As suggested by the reference paper [2], pure aluminium has an anode efficiency of 21.23% which can be increased by increasing zinc content from 1-8% and maximum anode efficiency is available at 6% Zinc which is 86.59%. This paper established that at this amount of Zinc, the formation of β phase will start which is confirmed from the Al-Zn phase diagram. This phase takes part in the breakdown of an aluminium oxide film by forming a galvanic cell within the α- Al matrix. This detailed phenomenon is studied in this paper. This β phase is more negative to the α- Al matrix so it will act as cathode and the α- Al matrix will act as anode and the dissolution of the α- Al matrix will increase. Thus, anode efficiency is increasing with an increase in Zn content.

As given information by the reference paper [21], in this case also the addition of Zn in pure Al will improve anodic oxidation of developed alloy and it is confirmed by developing Evans diagram for that alloy that shows shifting of potential in anodic direction.

4.2 Effect of Tin

Sn has less solid solubility in an aluminium matrix which is less than 0.002 atomic weight percentage and Sn forms a eutectic type of system with aluminium. Sn has maximum solid solubility of 0.10% between the melting point of Aluminum (660^{o}C) and eutectic temp (228.3^{o}C) is confirmed by the binary diagram of Al-Sn. [20].

In the reference paper [1] information has been provided regarding Sn addition in different proportions 0.01%, 0.05% and 0.1% respectively in Al-Zn-Mg alloy. Paper opines that anode efficiency increases with increasing Sn content and maximum efficiency available at 0.1 Sn which is 98.65% and it will also increase with a time exposure. This paper points out that due to the addition of tin in different proportions in the Al matrix, Sn globules will form in the matrix which will act as a nucleation site for the corrosion of the matrix and self corrosion of anode will improve progressively.

4.3 Effect of Titanium

Ti has solid solubility in the aluminium matrix which is 0.57 atomic weight percentage which is less than 1% and Ti forms a peritectic type of system with aluminium and forms an intermetallic phase with Aluminium. Maximum solubility occurs at peritectic temp which is around 665^o C [20].

This reference paper [22] clearly states that titanium acts as a grain refiner which affects the distribution of alloying elements within the matrix. This paper also communicates that Ti will form the second phase precipitates $TiAl_{3,}$ as the Ti content increases the number of precipitates increases and Ti also helps in the uniform distribution of Zinc & Indium through the Al matrix. Uniform distribution of alloying elements avoids segregation at the grain boundary and which will reduce intergranular corrosion. Also, corrosion uniformity & self corrosion due to the formation of second phase particles will be improved by Ti addition.

4.4 Effect of Titanium and Magnesium

Mg is a major alloying element in the 5XXX series[19] Mg has maximum solid solubility in an aluminium matrix which is 16.26 atomic weight percentage around 450^o C and Ti have solid solubility in an aluminium matrix is 0.57 atomic weight percentage around 665^o C [20].

A detailed study of this reference paper [23] clearly state that the addition of Ti and Mg in Al-Zn-In Alloy will give rise to the formation of $TiAl_3$ and $MgZn_2$ particles in Al matrix which are excellent nucleation site for the galvanic corrosion of anode. In this situation, the second phase particles of Mg and Zn act as anode and the passive film acts as a cathode. Due to this dissolution of the second phase particle in an aluminium matrix is observed. Now, these particles are more negative compared to Al-matrix so the micro galvanic cell is formed within the matrix in which particles act as cathode and dissolution of the Al matrix will start. This will increase self corrosion of anode. Ti also acts as grain refiner in the Al matrix so the addition of Ti also increases uniformity of corrosion and it will be beneficial to improve self corrosion.

4.5 Effect of Titanium and Zirconium

Ti and Zr have solid solubility in an aluminium matrix which is 0.57 and 0.085 atomic weight percentage respectively which is less than 1% and form a peritectic type of system with aluminium and form intermetallic phase with Aluminum. Maximum solubility occurs at peritectic temp which is around 665^o [20].

As suggested by the reference paper [24], Ti and Zr both act as grain refiner in Al-matrix. A detailed study of Titanium and Zirconium addition in Al-Zn-In alloy establishes that during solidification of alloy Zn is segregated at grain boundary which reduces the uniformity of corrosion and sometimes it will form interdendritc structure within a matrix and reduce self corrosion. Grain refiner reduces this effect and makes the alloying element uniformly distributed through the Al matrix. Ti will form the $TiAl_3$ phase which produces a good nucleation site for corrosion and the dissolution of Al-matrix will start. Due to the addition of grain refiner more finer & uniform structure will be produced which will promote more uniform dissolution and anode performance.

4.6 Effect of Silicon

Silicon is the primary element in the 6XXX series and they are heat-treatable alloys. [19] Si has maximum solid solubility in an aluminium matrix which is 1.59 atomic weight percentage around 1080° C [20].

As mentioned in the reference paper [15] after adding Si in Al-matrix it will form an equiaxed fine-grain during solidification which will reduce grain boundary segregation of Zn and improve corrosion uniformity. In presence of Mg, it will form Mg_2Si particles and these particles uniformly distributed at the grain boundary. These second phase particles of Mg and Si will act as a cathode and make an aluminium matrix anode. Silicon improves hardness, wear resistance and castability.

4.7 Effect of Lanthanum

Lanthanum has maximum solid solubility in an aluminium matrix which is 0.05 weight percentage at room temp and beyond that limit will give rise to form the intermetallic compound. As suggested by the reference paper [25] addition of La in Al-matrix will give rise to the development of Al-Zn-La phases i.e Al_2LaZn_2. This particle segregates at the grain boundary which inhibits grain growth so fine grain and a uniform structure will be formed after the addition of lanthanum. Second phase particles $MgZn_2$ also form within the matrix. As discussed in earlier cases these phases are more negative to Al-matrix; this will provide the formation of galvanic cells within the matrix in which particles act as a cathode and matrix will act as an anode. Thus, the formation of these particles will improve the dissolution of the Al matrix.

4.8 Effect of Gallium and Bismuth

Ga has solid solubility in an aluminium matrix which is 8.82 atomic weight percentage around 30° C and Bi have solid solubility in an aluminium matrix is 0.01 atomic weight percentage around 660° C which is less than 1% and form a monotectic type of system with the aluminium and form the intermetallic phase with an aluminium [20].

As discussed in the reference paper [26] during solidification Al-Zn-Sn, aluminium crystallises first because it has a high melting point compared to Zn, Sn & Bi and these segregate at the grain boundary. Ga and Bi reduce the number of precipitates at grain boundary along with a decrease in width of diffuse boundaries which in turn improving the uniform dissolution of alloying element in an aluminium matrix, distribution of alloying element which forms heterogeneous phases that will improve dissolutions of the matrix. Addition of gallium and bismuth form microstructure with small grains.

4.9 Effect of Titanium and Strontium

Ti and Sr both have solid solubility less than 1% in Aluminium at peritectic Temp[20]. As proposed by reference Paper [27] Ti will act as a grain refiner and Sr can modify the Aluminium structure. Here, they have added Titanium varies from 0.03-0.1 wt% and Sr varies from 0.01-0.05 wt% in Al-5Zn-0.02In alloy.

Experimental studies confirm that Ti will affect the current capacity of anode increasing by 12% at 0.03wt% Ti and also anode efficiency will improve from 77% to 87%. Generally, indium in the Al-Zn system tends to form an interdendritic structure or grain boundary which is reduced by the addition of titanium and also form $TiAl_3$ particle and the greater amount of formation of small grain. These changes will lead to improved performance of the alloy. Strontium acts as modifiers and improves current capacity by 7% at 0.01 wt% and improves efficiency from 77% to 83%; this is achieved due to the formation of intermetallics at the grain boundary and interdendritic places due to high Sr content

4.10 Effect of Silver

Silver improves the corrosion resistance of Aluminium and will promote stability of passive layers. As discussed in the reference paper [28], adding Ag in ranges 1.5 & 2.5 will improve hardness and strength of the alloy but decrease the current capacity of alloy. The corrosion potential of developed alloy occurs simultaneously with the pitting potential and above that potential passive layer is stable. So, from that, we conclude that Silver will shift the potential of Aluminium in a noble direction.

4.11 Effect of Selenium

Information obtained by the reference paper [29],studied the effect of Se in Al - 5% Zn alloy and kept Sn & Bi 0.10 wt%. They added Se 0.01%, 0.05%, 0.10% and 0.50% respectively and got the best result at 0.5% Se. That is 90% Anode Efficiency this is achieved due to the formation of Se inclusion will give metallographical improvement and form uniformly grain. Efficiency is improved from 71.% to 90% as Selenium increases.[29]

4.12 Effect of Gallium and Zinc.

As discussed in section 4.1 and 4.8 Zn and Ga have formed peritectic and monotectic systems with Aluminium respectively. Reference paper [30] proposed improvement in anode efficiency. They studied the effect of Gn and Also the synergistic effect of Zn and Ga adding 0-1wt% and Zn 0-4 wt%. Here, both the elements decrease corrosion potential as Ga increases from 2.6wt% shift corrosion potential in a negative direction up to 0.5 volts and Zn will reduce 0.1-0.3 volt.

4.13 Effect of Tin and Magnesium

As discussed in section 4.2 and 4.4 Sn and Mg have formed a peritectic system. The reference paper [32] will give an idea about the effect of Sn and Mg in Al-5%Zn adding Sn vary from 0.1-1.0 wt% and Mg vary from0.5-2.0 wt%. Both the elements will shift potential in the negative direction. This is because Sn distributes its particles locally on grain boundaries which affect the performance by increasing Sn up to 1.0% progressively shifted potential from -0.92 to -1.1 volt. Here, intergranular corrosion of alloy will give rise to the breakdown of a passive layer as a discontinued passive layer at the same time formation of the pit will be started. Mg will act as a grain refiner which reduces grain size from 150-200 micrometre to 70-100 m.

4.14 Effect of Copper

Copper is a major alloying element in 2XXX series Alloy. These are the heat treatable and natural aging alloy and have good strength. [32] Cu has 5.67% solubility at 550° C in Aluminium and form peritectic type of system with Aluminium.[14]

As mention in reference [16], Copper can affect the quality of oxide film, it will reduced density of oxide film and improve rate of amorphous alumina formation this will weaken the oxide film and leading to the breakdown of film and as we discussed section 3 pit formation is start at oxide free region. This will decrease corrosion resistance of developed alloy.

5. CONCLUSION

From the all above review we conclude that chemistry will play the most versatile role in corrosion morphology. The addition of the alloying element will change the chemical property of the sacrificial anode by forming another intermetallic, second phase particle and precipitates. The distribution of this new phase in the microstructure will alter the electrochemical and chemical properties of the sacrificial anode. All the alloying elements like Mg, Zn, Sn, Ga, Ti will improve electrochemical properties.

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Investigation of Al_2O_3 Nanofluid by Diluted Ethylene Glycol for Heat Transfer Application

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Abstract

Alumina based nanofluidsis a potential cooling medium for the various applications like electronic, transport and, industrial cooling applications etc.. In addition, alumina based nano fluids can be used as a coolant in satellite systems application. Alumina based Nanofluids can be synthesized by two different techniques such as single step and two-step method. In this work, two-step process was adopted for synthesis of nanofluid. Initially alumina particles were integrated by sol-gel method. By employing SEM, EDX and XRD, the synthesized alumina powder particle size, chemical composition and phase analysis were verified, respectively. For synthesis of nanofluid, the nano alumina particles were mixed with ethylene glycol and mixture of ethylene glycol and water by using ultrasonicator. The synthesised alumina based nanofluids properties were studied such as thermal conductivity, pH, viscosity and density using thermal properties analyser, pH meter, viscometer and specific gravity bottle, respectively. The comparison of both the nanofluids shows that thermal conductivity of ethylene glycol and mixture of ethylene glycol and water base nanofluid has average of 24 % higher efficiency over a range of temperature than other nanofluids.

Keywords:
Nanofluid;Alumina; Ethylene glycol;Nano particles;Thermal conductivity.

Nomenclature

Kα	The high intensity nearly monochromatic x-rays
v	Volume of water H2O
m	mass
ρ	Density of nanofluid
T	Temperature
k	Thermal conductivity

Greek symbols

α, β, γ	Thermal conductivity coefficients factors

1. Introduction:

The fast growth of technology focuses on the efficiency and minimization of the products or process. On controversy, it elevates the heat dissipation from machines/microelectronics which restricts the usage of product for long run. Technological support required for faster cooling medium to absorbs the dissipated heat. Conventionally, heat transfer problem solved by increasing heat dissipation area, then it moved to usage of fluid for heat transfer. Scientist tried various techniques to enhance the heat transfer. In 1873, Maxwell [1] proposed the composite fluids i.e. suspension of the particles in fluid, by considering thermal conductivity of solids is always higher than liquid. The coarser particle resists the movement of the fluid and tried to settle at the bottom. Based on the type of motion and nature particle, it may erode or corrode based on the nature of particles. In 1995, Choi [2] proposed the nanoparticles suspended fluid, coined the word nanofluids for heat transfer. Nanofluid overcome the technical

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hitches of conventional fluid, due to nano size, high surface area, able to suspend in liquid and high thermal conductivity of nanoparticles.

Nanofluids are synthesized by two techniques such as single stage and two stage method. The availability of various nanopowders, the cost effective two stage method was preferred for synthesis of nanofluids. The nanopowders are selected based on the ability to have stable and uniform suspensions, no reactivity with fluid and/ container etc. Several investigators studied influence nanopowders such as metals (Fe, Cu, Ag, Au etc.), ceramics (Al_2O_3, CuO, MgO etc.), coated metal powders (Au coated with thoriate, Ag coated with citrate etc.) and carbon based materials (single wall and multiwall nanotubes, graphene, graphene oxide etc.) in thermal conductivity of nanofluids [3]. The overall results indicate that quantity, shape, size and nature of nanoparticles plays a vital role. The thermal conductivity of nanofluids also depends on the specific heat capacity, viscosity, density and pH of the fluid. Several investigators studied about alumina based nanofluid in the water medium [4-7, 10], ethylene glycol [6, 8-10] and mixture of ethylene glycol and water mixture [10]. Reported that thermal conductivity of nanofluid is directly propositional to the volume fraction of nano particles. On controversy, volume fraction of nano particles reduces the viscosity of nanofluid. Based on this information, the focuses changes towards the size of nanoparticle [9].

In this work, the thermal conductivity of nanofluid is starting with the synthesis of alumina nanoparticles using sol-gel method. The effect on alumina particles in the thermal conductivity of base fluid of Ethylene Glycol (EG) and Ethylene Glycol + Water (EG-H_2O) mixture was studied over a range of temperature.

2. Experimental setup

2.1Materials and methods

Intially, nanoAl_2O_3particles were synthesized using raw materials such as aluminium chloride ($AlCl_3$), sodium carbonate (Na_2CO_3) and distilled water. Commercial high purity $AlCl_3$ and Na_2CO_3were mixed together in 1:1 in100 ml distilled water. To obtain the gel, the solution was heated at 150˚C in an oven for 10 hrs. To remove the volatile components in the gel, it was heated once again in a muffle furnace at 900˚C for 3 hrs under ambient atmosphere which results in white colour alumina powders. During the process, the following reactions were expected to taking place.

$$2AlCl_3 + 3Na_2CO_3 + 3H_2O \rightarrow 2Al(OH)_3 + 3CO_2 + 6NaCl$$

$$Al(OH)_3 \rightarrow Al2O_3 + H_2O$$

The surface morphology, particle size and chemical composition of the Al_2O_3nanoparticles were investigated by SEM and EDS of Tescan Vega SBH model. Using Cu Kα as a source, the crystalline phase of synthesis Al_2O_3 nanoparticles were obtained using Rigakuminiflex 600 XRD.

Concentrated Ethylene Glycol (EG) and the equal mixture of Ethylene Glycol and distilled water (EG-H_2O) were used a base fluid. The nano fluid were prepared by adding 1% volume concentration of nano Al_2O_3 particles into base fluid such as EG and EG-H_2O.Thesolution underwent ultrasonication for one hour at 50˚C to increase the stability and uniform dispersion of the particles in the medium. The properties of Al_2O_3-EG and Al_2O_3-EG-H_2Onanofluids such thermal conductivity, pH, viscosity and density were studied using KD2 Pro Analyzer , pH meter, Ubbelohde viscometer and specific gravity bottle, respectively. Figure 1 shows the overall synthesis and study process of alumina nanofluid using flowchart.

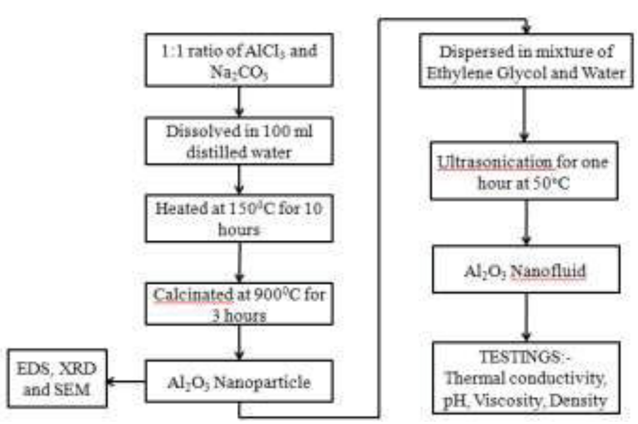

Fig.1.Various steps of in synthesis of Al_2O_3-EG-H_2O and Al_2O_3-EGnanofluids.

2.2. Characterization of Nanoparticles

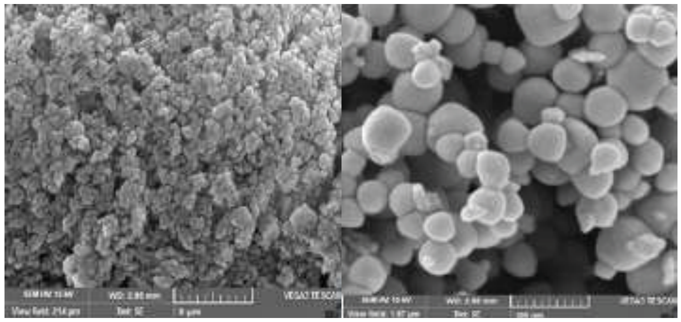

Fig. 2 Surface morphology of the Al_2O_3 nanoparticles with respect to two different magnifications

The surface morphology of synthesis alumina particles was shown in figure 2. It clearly shows that present sol-gel produces spherical alumina particle. The particle sizes were analyzed using Image J software. The particles sizes vary between 17 to 46nm and average of 30nm. Figure 3 shows the chemical composition so-gel synthesized Al_2O_3 nanoparticle. In addition, of aluminum and oxygen, reasonable quantity of sodium and chlorine was present in the product. It indicates that calcinations temperature or time was not sufficient to remove the unwanted volatile components.

Table 1. Al_2O_3 Chemical Composition details in percentage

Element	Weight%	Atomic%
Al	46.85	39.20
O	44.83	35.24
Na	5.79	21.49
Cl	2.53	4.07
Total	100.00	100.00

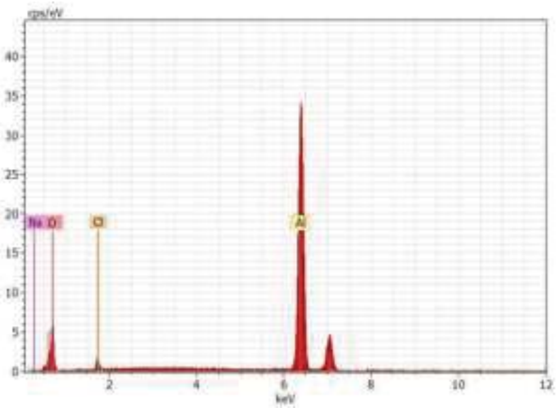

Fig.3Chemical composition of synthesis Al_2O_3 nnanoparticles using EDS

Thermal conductivity can be measured using thermal property analyzer i.e. KD2 Pro by way of the usage of KS-1 sensor needle. Thermal conductivity of the nanofluid can be measured at specific degrees of temperature such as from 30˚C to 90˚C and information calculated by means of test is mentionedinTable2. Figure 4 show the XRD pattern of Al_2O_3 nanoparticles. It also revealed presence of other phases due to sodium and chlorine.

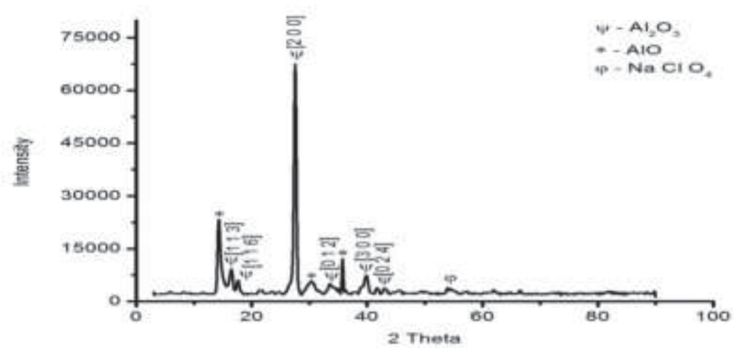

Fig.4. XRD pattern of Al_2O_3 Nanoparticle

2.3. Physical Properties of Nanofluids:

Thermal conductivity can be measured using thermal property analyzer i.e. KD2 Pro by way of the usage of KS-1 sensor needle. Thermal conductivity of the nanofluid can be measured at specific degrees of temperature such as from 30˚C to 90˚C and information calculated by means of test is mentionedinTable.3.

The volume of measured quantity of alumina nanofluid in concentrated and diluted ethylene glycol was measured with the help of gravity bottle at temperature from 30 to 70˚C. The mass (m) of water (H_2O), ethylene glycol ($C_2H_6O_2$) and alumina (Al_2O_3) were fixed. The density of nanofluid (ρ) is calculated by the formula, which is given below.

$$\rho = \frac{m}{V}$$

Figure 5 shows the measured density of alumina nanofulid in concentrated and diluted ethylene glycol. Due to volume expansion of solution with respect to temperature, density of nano alumina dispersed fluid decreases irrespective of the medium. The atomic mass of ethylene glycol is 3.45 times greater than water. Hence, alumina in diluted ethylene glycol is lower than concentrated ethylene glycol.

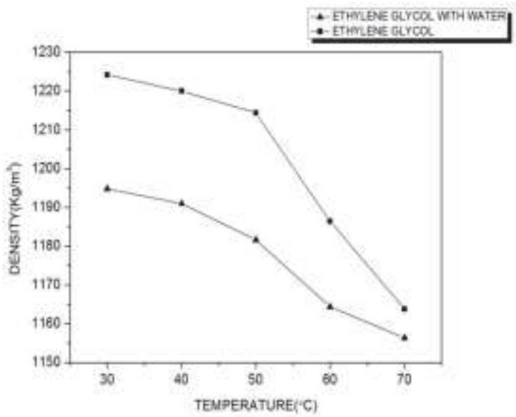

Fig.5Calculated density of Al_2O_3-EG-H_2O and Al_2O_3-EG

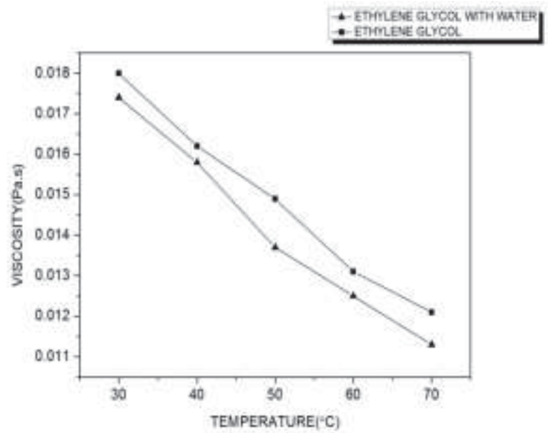

Fig.6. Measured viscosity of ofAl_2O_3-EG-H_2O and Al_2O_3-EG.

Viscosity of concentrated and diluted ethylene glycol based nano fluid compared with respect to temperature between 30˚ to 70˚C. The density and temperature influences the viscosity, which reflects in the figure 6. As the expansion of fluid due to temperature raise, the resistance against the flow falls.

The ethylene glycol pH value lies normally between acidic and neutral such as 8 to 5.5 based on the water content. The measured pHvalueofAl_2O_3basednanofluids in the medium of concentrated and diluted ethylene glycol is 9 and 8.5 respectively. It may be due to presence of sodium and chlorine ions also possible in the present scenario.

Thermal conductivity of Al_2O_3-EG-$H_2O$and Al_2O_3-EGwas compared in figure 7. The standard thermal conductivity of ethylene glycol, water and solid alumina at 25^{o}Cis 0.253, 0.613and 40W/(m.K), respectively [3]. As per rule of mixture, equal preposition of ethylene glycol and water thermal conductivity is 0.433W/(m.K). Hence, ethylene glycol and water based fluid even with small quantity of alumina induces the thermal conductivity. When nano alumina particles were added to fluid, partially the heat energy was absorbed by particles, which impacts on the vibration and diffusion rate of particles in the fluid. In addition, the size and spherical shape of the nanoparticles also soundlessly contributes for thermal conductivity of nanofluids. High fluidity and volume of EG-H_2O fluid significantly raised the diffusion of alumina nano particles which reflects in thermal conductivity. The thermal conductivity efficiency of Al_2O_3-EG-H_2O nanofluid as an average of 24% higher than Al_2O_3-EG nanofluid.

Using regression analysis, the variation of thermal conductivity (k) as the function of temperature (T) yields the polynomial relationship of second order equations as,

$$k = \alpha + \beta T + \gamma T^2$$

The coefficients α, β and γ for Al_2O_3-EG-$H_2O$and Al_2O_3-EG are listed in table 2. The deviation around the temperature 50 ^{o} to 70^o C may be due to presence of impurity phase present in the nanoparticles. Thermal conductivity purely depends on the nano particle size and the comparison values are listed in table 3.

Table 2. The coefficients α, β and γ for Al_2O_3-EG-$H_2O$and Al_2O_3-EG

Nanofluid	Coefficients in W/(m.K)			R2
	α	β	γ	
Al_2O_3-EG-H_2O	0.6816	-0.0049	0.0001	0.9942
Al_2O_3-EG	0.2603	0.0048	0.00002	0.9948

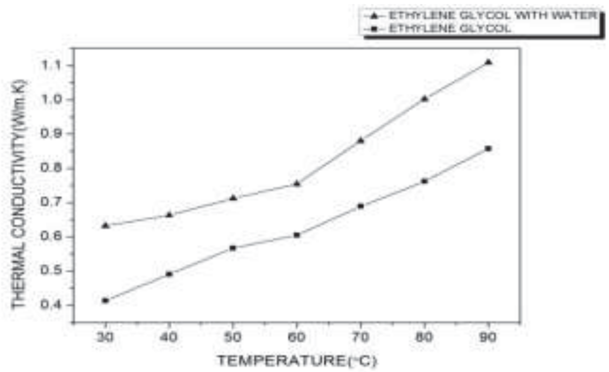

Fig.7.Measured thermal conductivity of Al_2O_3-EG-H_2OandAl_2O_3-EG nanofluid.

3. Result and discussion

In the present study, the alumina nano particles was synthesized by using sol gel method. The chemical composition analysis revealed that significant quantity of sodium and chlorine in addition to aluminium and oxygen. It indicates the calcination temperature has to be identified using differential thermal analysis. The thermal conductivity of the nanofiluid is depands on the nano practical size and the average particle size of synthesized Al_2O_3 nanoparticles is 30nm. Due to presence of impurities such as Na and Cl, additional phases are identified by XRD analysis. Using ultrasonicator, then a no Al_2O_3 particles were dispersed uniformly in ethylene glycol (EG) and ethylene glycol-water (EG-H_2O) for synthesis of nanofluid. The nanofluid of Al_2O_3-EG-H_2O and Al_2O_3-EG properties such as density, viscosity, pH and thermal conductivity with respect to temperature 30ºC to 90ºC was measured.

Table.3 Thermal conductivity values in different nano particle size

S.No	Nanofluid Particle	Base fluid	NanoFluid particle Size (nm)	Maximum % of enhancement	References
1	Al_2O_3	Water/EG	38.4	10	Lee S,ChoiSUS[5]
2	Al_2O_3	Water/EG	28	16	WangX,XuX [9]
3	Al_2O_3	Water/EG	60.4	23	Xie H,WangJ [23]
4	Al_2O_3	Water/EG	38	11	Kim SH [24]
5	Al_2O_3	Water	8-282	20	Beck M,YuanY [25]
6	Al_2O_3	EG	12-282	19	
7	Al_2O_3	EG	17-46	24	Present work

4. Conclusion

The following conclusions are derived from the observations.

- As expected, density and viscosity of nanofluids are decreases with temperature. The nanofluid Al_2O_3-ethylene glycol-water mixture nanofluid has low density and viscosity compared to Al_2O_3- ethylene glycol irrespective of temperature due to physical properties of water.
- Thermal conductivity of Al_2O_3-ethylene glycol-water mixture nanofluid has higher thermal conductivity than Al_2O_3-ethylene glycol due to density, viscosity, particle size and shape.

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A Review of Compliant Mechanisms Manufactured by using 3D Printing Technology

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Abstract

3D printing is emerging as a revolutionary manufacturing process for the future. Presently 3D printings are mostly being used in prototyping, but with rapidly changing designs and need of customization it will emerge as new go to manufacturing technology. With its capability to produce complex part easily and new material being developed with high capabilities for 3D printing, we see it being used in advanced application like bioengineering, aerospace, robotics etc. Compliant mechanism is mechanism without any joints, which means entire mechanism is made of one part eliminating joints and thus reducing size of the mechanism. When compliant mechanisms are produced with 3D printing manufacturing becomes convenient and mechanism thus produced finds it application in many areas due to its compact size and reduced number of parts. This paper gives introduction to commonly used 3D printing technology and compliant mechanism, and analysis use of 3D printing to develop compliant mechanism for different application along with their merits and demerits. Different materials used in various applications are also discussed. In conclusion this study suggests many possibilities of application of 3D printed compliant mechanism especially in aerospace and micro-robotics.

Keywords: 3D printing; compliant mechanism; FDM; Additive manufacturing; Monolithic Mechanism.

1. Introduction to 3D printing and compliant mechanism

Nowadays 3D printing is one of the growing technologies in which method of additive manufacturing is used to create three-dimension parts with ease. In additive manufacturing as the name suggests, additive process is used to make parts in which with the help of nozzle it creates bed first and starts its process and after creating successive layers 3D printed parts are manufactured. If one takes cross sectional area of final part then he can observe each layer placed horizontally. In subtractive manufacturing, extra material is removed whereas additive manufacturing is opposite method in which instead of cutting layers are added to form part.

Moreover, with the help of combination of 3d printing and compliant mechanism one can cope up with rapid prototype production, cost issues and properties like flexibility, strength and many more. 3d printing is considered as ideal method for the producing any type of complex compliant mechanism due to its flexible nature. Moreover, Compliant mechanisms obtain its motion from the elastic deformation [1] Compliant mechanism is very helpful in the small-scale robots and with the use of that we can avoid two parts in contact [2]
With the help of compliant mechanism, we can achieve mainly two things Reduction in parts = less weight, Reduce manufacturing complexity [2]
If we take example of 3D printed compliant gripper then compliant part helps to prevent any damage of object which is helpful in material handling [3,4]

Compliant mechanism is easy to produce with 3D printing technology and have found their application in many fields such as robotics, space applications, micro and Nano systems, biomedical engineering etc.

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Fig. 1 3D Printed Compliant Gripper [5]

3D printing will improve compliant mechanisms with lighter materials and new design solutions such as interlocking of parts or hollowing of part body. But most importantly, one can actually design a mechanism that can be fully 3D printed in one piece. The main methods of 3D printing are as follow.

1.1 FDM (Fused Deposition Modelling)

It works by extruding material through a nozzle to print one cross section of an object [6], followed by lowering the platform so that it can continue further for a subsequent layer [7]. Moreover, the initial point of the printer contains type of heating device which liquefies wire as soon as it passes through the nozzle and a new layer is formed. Some important benefits of FDM are inexpensive, lightweight, fast and easy procedure. On the other hand, it also had different limitations like fragile mechanical properties and substandard exterior characteristic [8]. Moreover, it had limited number of thermoplastic materials which can be used as materials [9].

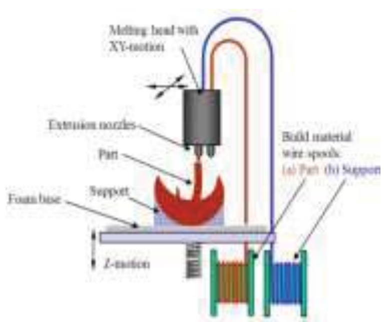

Fig. 2 Fused deposition modelling [10]

1.2 Poly-jet 3D Printing Technique

It is unique type of additive manufacturing process proficient to employ rigid as well as pliable material sectors into a one stop production, making it specially licensed for construction of complex and conglomerate compliant mechanism. It offers true-colour print, with a film width of 16-30 micro meter and obedient design of 42 micro meters [10]. Moreover, here we can combine two materials simultaneously in different proportion to form nine gradient material whisks.

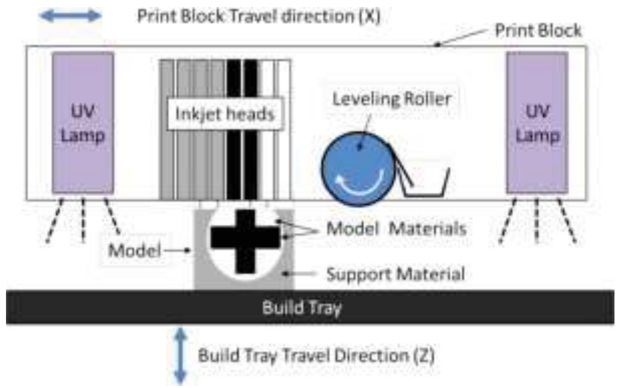

Fig. 3 Demonstration of unswerving 3D Poly- Jet printing method [11]

1.3 Electron Beam Melting (EBM)

Due to drawbacks of FDM method and poly-jet 3d printing and to make complex parts of titanium electron beam melting is created. EBM is type of 3D printing in which metal powder are melted together and with the help of that it makes successive layers [11]. In EBM, Designation of parts is made with reduced manufacturing constraints. With the other types of 3D printing, we are not able to make compliant mechanism in metal form but with the help of this technique we are able to make metal monolithic structure [11]. EBM allows us to make monolithic structure in such way which is not possible by any other method of 3D printing.

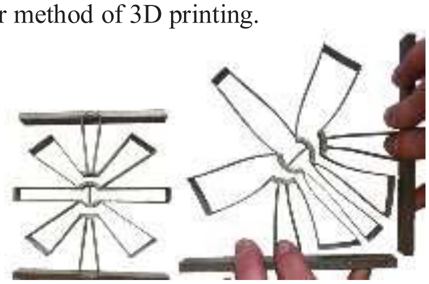

Fig. 4 A Complaint titanium hinge made with EBM. It has efficient of -90* to +90* of movement [12].

1.4 Stereolithography (SLA)

Stereolithography, which was developed in 1986, is also part of oldest practices of 3D printing [13]. SLA builds parts from top to bottom. In this technique UV light or electron beam is imparted on layer of monomer or resin to initiate a chain reaction to create polymer. This one layer of polymer supports the next layer and part is produced layer by layer. It can also print ceramic polymer composite [14,15]. SLA prints true quality components at accurate resolution starting 10 micro meters [16]. On the other hand, it is comparatively decelerated, costly and only few materials are available for the printing. Also, kinetics of the reaction generating procedure is complex. The vitality of light origin and exposure are the key constituent managing the size of particular plane [17].

2. Merits of 3D printing

There are several upsides available for 3D printing from which few are mentioned below.

The main advantage of 3D printing is rapid manufacturing compare to conventional techniques in the result we can save lots of time. Another merit off this technology is rapid prototyping. Nowadays, we all are interconnected across the globe and because of this technology we can make any kind of prototype in rapid mode. Moreover, the amount of cost it takes is very less compare to other methods. Another exciting feature of this method is that we can make object anywhere, it means it does not require heavy investment in production facilities. Nowadays, we are living in the zone where monitoring of pollution matters a lot. So, 3D printing in that matter is pollution free technology

3. Demerits of 3D printing

Since various methods are used to manufacture compliant mechanisms on contrary it also has some drawbacks. This demerit varies from method to method. Mainly, they are dependent on the various factors such as thickness of the prototype, orientation, raster angle, air gap etc. [7]. Although FDM is widely used and cheap method due to layer-by-layer configuration quality of surface is not good compare to conventional method [18]. Moreover, in these techniques stiffness problems arrive because in 3D printing different orientation gets different results [19]. In 3D printing while analysing and characterising, we should not treat component as a material property but instead of that we have to treat them as a structural property [7].

4. Development of compliant mechanism

Development of 3D printed compliant mechanism is based on two domains which are listed as below.
Firstly, that is synthesis methodology which defines desire degree of freedom, high stiffness, large work space, large dynamic response with high frequency. Secondly, fabrication technology defines the performance of complaint mechanism [18].

4.1 Different types of compliant mechanism [20]

- Compliant mechanisms with path generation
- Compliant mechanisms with multiple degrees of freedom
- Compliant mechanisms with multiple physics
- Compliant mechanisms with multiple materials

4.2. Benefits of compliant mechanism over conventional mechanism

Due to elimination of certain factors, it is possible for Monolithic mechanisms to achieve high performance in two or more axis setup [11]. Moreover, there are several other benefits of compliant mechanism which include reduce part count, decrease in the assembly time, less maintenance, comparatively low weight, cost effective and alternative of traditional rigid linkage mechanism [21]. It not only prevents vibration during high speed but also eliminate the requirement for lubrication [22]. Also, complaint mechanism is able to provide the precise motion during its operation [18].

An example of conversion of conventional mechanism to compliant mechanism is given as below from which we can easily define the problem and find the solution.

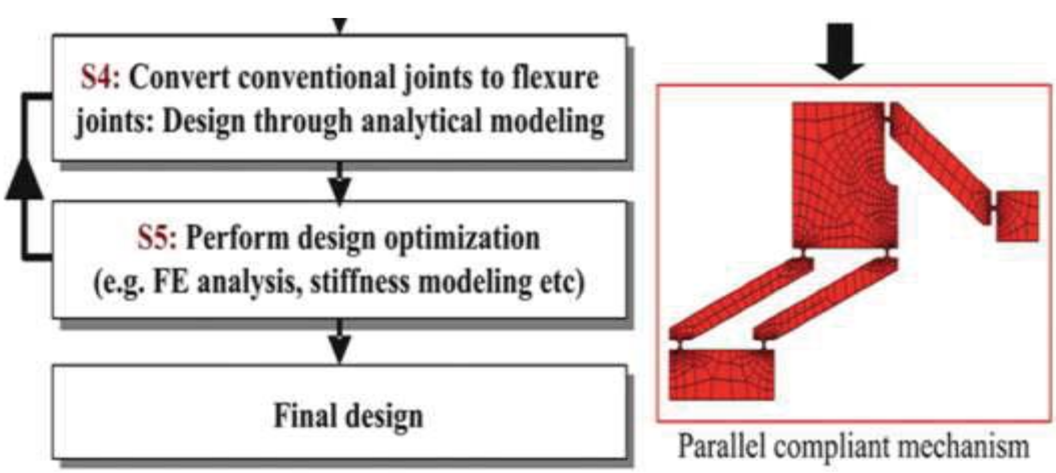

Fig. 5 Linkage-joint made up of parallel-kinematic architecture and parallel compliant mechanism [23]

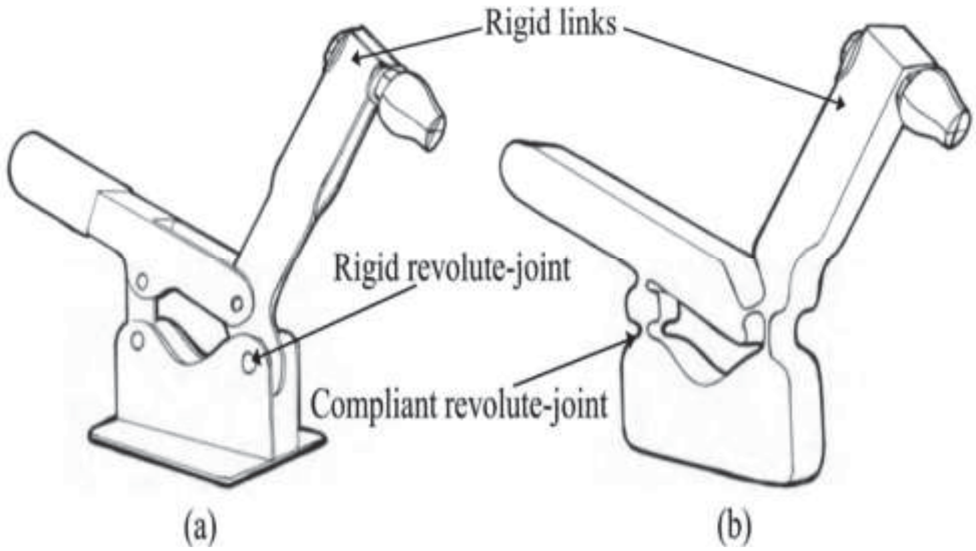

Fig. 6 Comparison between two joints made by different process [23]

From above figure (a) we can easily say that 2 joints which are made of conventional method of using bolts can easily convert in to figure (b) where it can be seen that two joints are made of monolithic connectors which has many advantages for instance, less material, easy design, and the main is reduction in cost [23].

4.3 There are several upsides of compliant mechanism which are mentioned as below:

1. The foremost advantage of compliant mechanism is there no need of assembly.so; the total structure is monolithic [16].
2. In this structure there is no need of lubrication so it reduces total cost of material [24].
3. Another most important factor is reduction in total number of parts results in less weight [24].
4. Designs are uncomplicated to unite with contemporary actuators [24].
5. Backlash can be eliminated, which is also great advantage [24].
6. Also, this non assembly structure has wide scope in medical industry in prosthetic body parts for instance, finger, hands, legs, bones replacement etc. [25].
7. Complex control system can be replaced by a compliant mechanism such as constant stiffness mechanism [26] and constant force mechanism [1].

4.4 There are also some demerits of monolithic mechanism which are given as below:

In this structure flexure pivot has restricted scope of motion because of configuration and stuff possessions [25]. Moreover, another significant problem is conventional flexure has bad structural effects exhibited when subjected to two or more axes freight [25].

- Due to presence of large deflections in compliant mechanism which ultimately cause increase in nonlinearities in both material behavior and geometry.[27]
- Also, in compliant mechanism direction of layer play a vital role to vary the stiffness by orders of magnitude.[27]
- High stress concentration must be kept away in order to reduce the risk of failure and material fatigue due to faulty design.[27]

It is concluded that there is difficulty in analyzing and designing complaint mechanisms [10].

5. Comparison of 3D printing with conventional methods for manufacturing compliant mechanisms

For compliant mechanism processes are selected on the basis of their characteristics. Here three processes are mentioned and selections of them in different applications are divided into mainly three criteria. First of all, large size mechanism in which moulding method is more advisable. Secondly, complex size and millimetre size mechanism in which 3D printing is more preferable. Lastly, in the mechanism which possesses high strength then in that case milling method is more advisable [28].

5.1 Materials and their applications in compliant mechanism

- The most common materials which are used in elements of compliant mechanism are mainly gold, epoxy resins, silicon and acrylic, polymethyl methacrylate. Moreover, widely used materials for micro compliant mechanism are mono and polycrystalline silicon, silicon nitride, nickel and copper [28].

- Another commonly used material is thermoplastic elastomer (fila flex) which is applicable in soft robotic finger [29].

- Combination of two or more material can be used as demonstrated by John A. Mirth where they used PLA and ABS using Fused Filament Fabrication method [30]

- PA2200 based on polyamide 12 is also convenient because of its biocompatible characteristics and used in 3D printed robot which is used in ENT surgery [19]. Further, high strength nylon plays an important role in compliant mechanism of three phalanax under actuated prosthetic finger [21]. Polyurethane is also an important material which has multiple usages namely interlocking joints for locking 3D printed components simultaneously, joining panels in automobile and construction factories [22].

6. Conclusion

- Compliant mechanism is used in many special applications and 3D printing is turning out be go to method of manufacturing this component.
- Some applications of compliant mechanism require a custom design such as in the case of prosthetics.
- 3D printing is a viable option to manufacture this kind of custom part where conventional methods are more suitable for mass production.
- There are relatively a smaller number of materials available to manufacture this component which limits their use and capabilities.
- Also Design of compliant mechanism is a complex and difficult task.
- With the growing use of compliant mechanism and development in 3D printing technology one can conclude that 3D printed compliant mechanism has great potential for special applications.

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A Study on Process Parameters of Fused Deposition Modelling Assisted Investment Casting

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Abstract

Now days, FDM process is widely applicable in many field of manufacturing. Materials used are consumable and can be formed into desired shapes for this reason; FDM process is assisting in investment casting (IC) process. FDM is suitable for making patterns for investment casting because of its capacity of producing very small and complex parts. Different process parameters are responsible for quality and accuracy of parts produces by rapid investment casting. Better quality products can be produced without additional cost of hard tooling by proper adjustment of process parameters. Machining economics and product value can be developed to great level by optimizations of machining parameters. This review paper is aimed to find out how different parameters of FDM process affect the accuracy and quality of part produced.
Keywords: Fused deposition modelling; Investment casting; casting patterns

1. Introduction

To produce complex and intricate parts investment casting is one of the suitable processes. However, in prototyping, design optimization, customized and specialized component productions and design iterations if the required numbers of pieces are less; use of the investment casting with high cost of tooling marks prohibitively costly. With the help of 3D printing, one can directly produce parts without necessity of costly tooling (Vyavahare et al. 2020). Without use of costly tools, RP technologies can produce patterns directly, so rapid investment casting is suitable for any type of low or higher grade of production (Rosochowski and Matuszak 2000). With FDM process, any complex shapes can be produced without wastage of material and with shorter time (Wang et al. 2018).

2. FDM working principle

In late 1980's, the FDM technology was established and numerous series of machines were developed (Bakar, Alkahari, and Boejang 2010). In FDM printer thermoplastic materials are used as raw material. In FDM working process, the raw material is extruded on the base of the printer in the form of layer through the heated nozzle. After one layer solidifies the next layer is extruded. In this way the object is built from bottom to up layer by layer. In some objects, there is need to give some support to build the part. There is provision in the 3D printer so that support structures are printed with the object. Later on these structures can be removed. Flow of material can be controlled through the nozzle which has a programmed mechanism to on and off or direct the flow of material (Kumar, Ahuja, and Singh 2012).

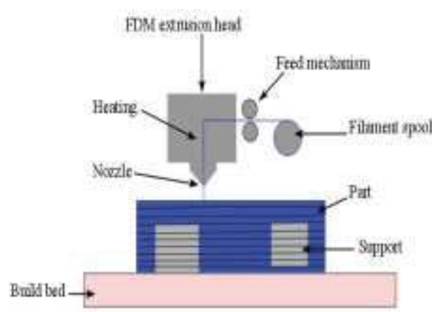

Fig. 1. Schematic of FDM (Alafaghani et al. 2017)

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3. Role of additive manufacturing in Investment casting

The additive manufacturing techniques are being used in the several fields of production. Rapid prototyping technologies can produce patterns without use of costly tooling (Grimm and Grimm 2002). In conventional IC, wax is poured into the metal die and patterns are prepared. Due to brittleness of the wax, patterns are damaged while transporting them to foundry. Also the cost of die is big issue for small production. In rapid investment casting the patterns are made from thermoplastic material so above problems are unraveled. The fused deposition modelling (FDM) is used in investment casting to make different patterns with different materials with different complex shapes (Bassoli et al. 2007; Sivadasan 2012).

Research was made on conversional casting and rapid investment casting, it was found that rapid casting is more suitable as sacrificial pattern comparing with casting (Dickens et al. 1995). The applications of Additive Manufacturing in the field of casting have reduced the time and cost of manufacturing by 50 %. If Additive Manufacturing technology applied to conventional investment casting, it is known as "rapid investment casting" (Kumar, Singh, and Ahuja 2013)

4. Proposed methodology for literature review on FDM

For the literature review author proposed methodology based on different criteria of FDM in casting is shown in Figure 2. Literature is categorized base on out parameters; input processing parameters, optimization methods used, and some new processes used for FDM process optimization. Finally this article focused on how different processing parameters distress on quality of part produced with FDM, which optimization methods can be used for the best output with combination of various input parameters.

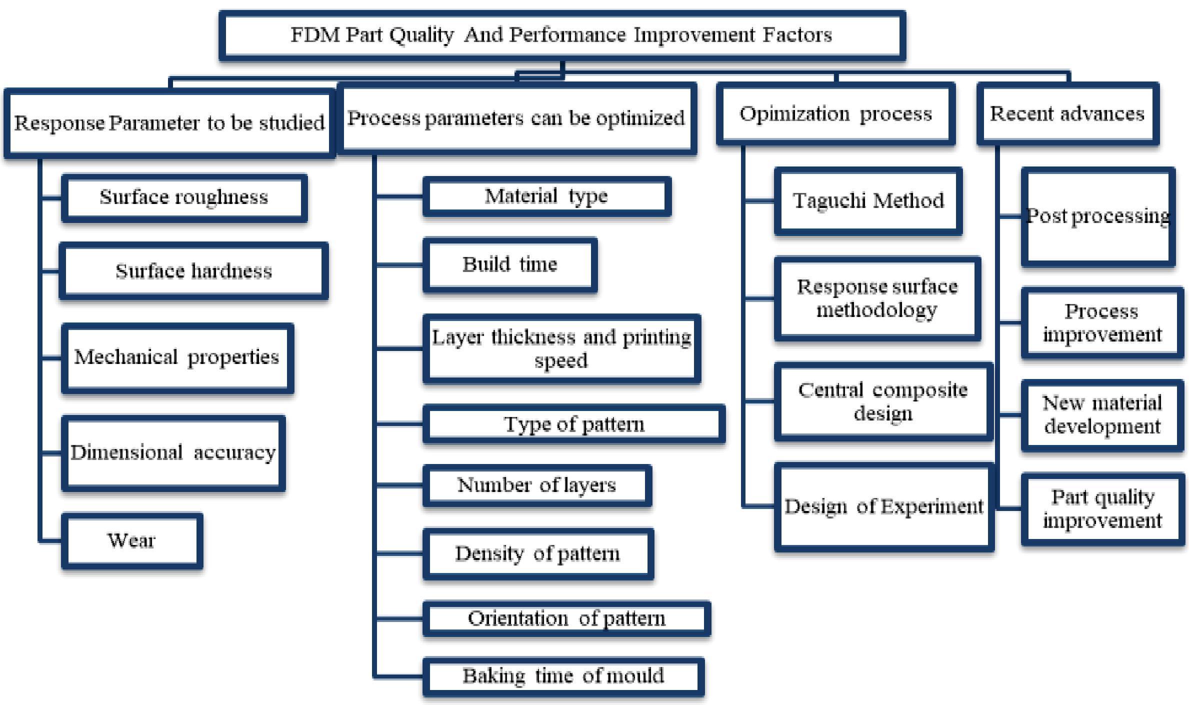

Fig. 2. Classification of literature review on fused deposition modeling and its application in investment casting

5. Parameters that are important in RIC

5.1 Dimensional accuracy of FDM printed patterns

In investment casting patterns dimensional accuracy is a big issue. Casting produce would be defective if the pattern is not correct. Research was made on finding methodology to compute volumetric error of the parts (Masood, Rattanawong, and Iovenitti 2000). Study developed mathematical technique to determine the optimum parameters to obtain dimensional accuracy by FDM. Result was confirmed with actual and experimental dimensions.

Shrinkage of the part found one of the effective parameter on the dimension. Study shows more shrinkage is found in length and width while in thickness direction positive eccentricity is there (Sood, Ohdar, and Mahapatra 2009). Many studies also found best setting of different parameters to increase the dimensional accuracy by using Taguchi's design method and other optimization methods (J. Singh, Singh, and Singh 2017). Orientation while preparing pattern on 3D printer is also effective parameter for dimensional accuracy. Accurate accuracy is found at 900 orientation (Garg, Singh, and Ips 2017).

5.2Surface roughness of FDM printed patterns

In moulding and parts assembly surface finish plays significant role. Surface condition of master patterns is replicated by the mould. To produce quality products, patterns must have proper finish to produce good castings. Surface finish of FDM part is influenced by various conflicting factors individually or interacting with others (Garg et al. 2017). Surface roughness can be reduced by chemical treatment or post processing treatment (Tiwary et al. 2019).

Construction of pattern both hollow and solid does not affect much on surface roughness. Percentage thickness of each layer affect the surface roughness of the side faces, while upper surface gives better quality as compared to bottom surface for both type of construction of patterns (Harun, Safian, and Idris 2009). Post processing treatment is significantly affective to reduce the surface roughness. Chemical treatment provides lower surface roughness (up to 0.30 μm) and better surface finish of FDM parts (Tiwary et al. 2019).

Many researchers worked on the surface defects and causes of it on FDM produced object. They also suggested different parameters optimum setting to reduce the errors (Kumar et al. 2012).

5.3Surface hardness

When there is surface contact between two moving parts, the surface hardness plays vital role in casting. For these kinds of engineering applications surface hardness must be acceptable to reduce wear of the parts. Some studies have been presented to show the effect of different parameters on the surface hardness. Several surface finishing methods like vapour smoothing, surface coating, nitrogen implantation, etc. found effective to increase the hardness of the components (Asgari et al. 2011, 2012; Carneiro et al. 2020; Ganesh et al. 2009). Cooling rate is one of the affecting parameter on surface hardness (Garg et al. 2017). V/A ratio is affecting parameter on hardness of the produced part. For better hardness smaller V/A ratio is preferable (Garg et al. 2017).

5.4Mechanical Properties

The patterns must have adequate strength so that it should not get ruined during casting operation is to be carried out in the foundry. To improve strength of the FDM produced part many research works has been done and shown effect of different parameters (Rohde et al. 2018).

The air gap and raster orientation are greatly affected parameters on the tensile strength of an FDM part. Bead width, model temperature, and color are less affecting parameters (Lee et al. 2007). FDM produced parts measured anisotropic characteristics so the strength of the parts depends on the raster direction and it was not affected by build direction. Other studies shows that impact strength of FDM parts is greatly affected by pouring temperature and less affected by coating thickness (Bhati et al. 2020). Pouring temperature also affect the impact strength of the part. For Aluminum alloy pouring temperature is kept 7000 C to get maximum impact strength (Bhati et al. 2020).

Author has reviewed some research papers on the input parameters and its effect on response parameters of the FDM process and summarized main findings in the table1.

Table 1. Summary of research papers on FDM process parameters and main findings

Researcher	**Material**	**Process parameters**	**Response**	**Tool/Method used**	**Findings**
(Dickens et al. 1995)	Wax	3D Rapid processes	Accuracy, surface finish	Rapid processing applied to different foundries	RP can be applied in casting but wax can be used as FDM material but due to brittleness they should be handled with care.
(Masood et al. 2000)	Plastic	Different shapes of the part	Volumetric error	Mathematical model	Analytical and practical results show good agreements.
(Pandey, Reddy, and Dhande 2003)	ABS	Build orientation, layer thickness	Surface roughness	ANOVA	Prediction of model good agreements with experiments.

(Anthony 2004)	ABS	Layer thickness	Mechanical properties (thermal expansion, tensile strength, flexural strength)	Dynamic Mechanical Analysis(DMA), ANOVA	Layer thickness influences the tensile strength of FDM parts.
(Lee, Abdullah, and Khan 2005)	ABS	Air gap, Raster angle, Raster width, Layer thickness	Elastic performance	Taguchi method, signal-to-noise ratio, and analysis of variance	Layer thickness, raster angle and air gap significantly affect the part.
(Ahn et al. 2009)	ABS	Layer thickness, surfaces angle, c/s of filament	Roughness	Mathematical equation	Computed value and empirical values validate each other.
(Galantucci, Lavecchia, and Percoco 2009)	ABS	Tip dimension, raster width, slice height, chemical treatment	Surface finish	Contact and non-contact optical system	Effects of parameters are optimized and chemical treatment found to be useful in obtaining better surface finish.
(Galantucci, Lavecchia, and Percoco 2010)	ABS	Chemical treatment	Mechanical Properties, surface quality	Central Composite Designs (CCD)	Chemical treatments improve the surface finish of the part.
(Chhabra 2011)	Aluminum	Shell mould wall thickness, layer thickness, part orientation	Dimensional accuracy, surface roughness	Z-casting (pattern less casting)	Reducing shell mould wall thickness produced better quality parts
(Chang and Huang 2011)	ABS	Contour width, Contour depth, Part raster width, Raster angle	Profile error, extruding appearances	ANOVA	Contour width is significant factor for profile error.
(Kumar, Singh, and Ahuja 2015)	ABS	Layer thickness, type of support, model interior and scale	Dimensional deviation, surface roughness, micro hardness	Solid works design software	By assisting of FDM process in the investment casting, hybrid method of production was developed.
(Boschetto and Bottini 2015)	ABS	Layer thickness, deposition angle	Roughness	Mathematical formulation	Barrel finishing action deeply affects the profile of the parts.
(Belter and Dollar 2015)	ABS-P430	Print orientation	Part strength	Instron Testing system	Process of fill compositing made low value parts.
(Christiyan, Chandrasekhar, and Venkateswarlu 2016)	ABS + composite material	Layer thickness, printing speeds,	Tensile strength, flexural strength	Universal testing machine	To obtain better tensile and flexural strength there is need of low printing speed and low layer thickness.
(Boschetto and Bottini 2016)	ABS	Deposition angle, layer thickness	Dimensional accuracy	Mathematical formulation	Analytical result shows good agreement with practical.
(J. Singh et al. 2017)	ABS+	Drying time of coating, and thickness of the mould	Dimensional accuracy and surface finish	ANOVA	Significant factors for 4 different processes have been found.
(Garg et al. 2017)	ABS	Type of Pattern, Ratio of volume and area, Orientation of the Pattern, Pattern density, Thickness of the mould,	Dimensional accuracy, surface finish, and surface hardness	Taguchi design of experiments, ANOVA	Ratio of volume and area, Orientation of the Pattern, and thickness of the mould are influencing parameters.

(Alsoufi and Elsayed 2017)	PLA	Angular direction, nozzle diameter, layer height, build time, print speed	Surface roughness	OriginLab® 2017 software	Nozzle diameter, layer height influence the most surface roughness
(Rohde et al. 2018)	ABS and polycarbonate	Raster angle, build orientations,	Anisotropic behavior	Universal testing machine	Anisotropic behavior was found with different values of parameters.
(Fernandes et al. 2018)	PLA	Infill Density, Extrusion Temperature, Raster Angle, Layer Thickness	Ultimate Tensile Strength, Yield Strength, Modulus of Elasticity	ANOVA	Optimum value of the parameters are found
(Dakshinamurthy and Gupta 2018)	ABS	Raster angle, slice height, raster width	Visco-elasticproperties	Taguchi Approach	Slice height and raster width are affecting parameters.
(Armillotta, Bellotti, and Cavallaro 2018)	ABS plus-P430 [60]	Layer thickness	Part dimensions	ANOVA	Increased layer thickness reduces the surface finish and has moderate effect on warpage of the part.
(Singh and Gupta 2019)	ABS	Part orientation, number of slurry coating layers, temperature	Hardness	ANOVA	Melting temperature plays significant role on hardness
(Bhati et al. 2020)	A-359 aluminumalloy	Pouring temperature, pouring time, coating thickness	Impact strength	Taguchi method	Pouring temperature plays significant role on strength.
(Kumar et al. 2021)	poly(ethylene glycol) di acrylate	Finite element formulation with stiffness regions	Topology optimization setting	ABAQUS analysis	Optimized results are validated with software.

6. Input Process parameters

6.1 Material

Light weight, low cost and high strength of polymer and its composites cause them on higher demand in all manufacturing industries. Research studies found parametric solution for different material compositions in FDM (Subramaniyan et al. 2020). Standard materials used in FDM are PLA, ABS Wax, polyethylene, polypropylene etc..

Some study shows ABS built pattern is suitable for rapid investment casting and it is having more quality advantages comparing with other additive manufacturing materials (Gouldsen 1998). Type of material also plays significant role on the hardness of the part.

Table 2. Categorization of reviewed literature related with optimization of process parameters on the base of materials

Material	**Researcher**
ABS	D. Ahn. 2009, S. H. Ahn 2002, Anthony 2004, Bakar 2010, Boschetto & Bottini 2016, Boschetto & Bottini 2015, Chang & Huang 2011, Coogan & Kazmer 2017, Dakshinamurthy & Gupta 2018, Galantucci 2010, Galantucci 2009, Garg. 2017, Gouldsen 1998, Harun. 2009, Kumar. 2015, B. H. Lee. 2005, C. S. Lee. 2007, Pandey. 2003, D. Singh 2020b, D. Singh 2020a, D. Singh, Singh, Boparai 2018, J. Singh 2020, Ranvir Singh 2019, Rupinder Singh & Gupta, 2019, Sood 2012
ABS+	Alsoufi & Elsayed, 2018, J. Singh 2017, J. Lee & Huang 2013
PLA	Alsoufi & Elsayed 2017, Fernandes 2018, Rajpurohit & Dave, 2018, Rajpurohit and Dave (2018b)
PC	A. Boschetto & Bottini, 2014, Salazar-Martín 2018, Tanikella 2017, Rohde 2018, Alsoufi & Elsayed, 2018, Singh 2018
ABS + hydrous magnesium silicate	Christiyan 2016
ABS, Nylon	Rupinder Singh 2016, Vishwas 2018
ABS, Polycarbonate	Rohde 2018
Wax	Dickens1995

6.2 Build time

Building time for any object depends on the height of the object in Z direction. So, to reduce the build time designing of object with less overall built height is necessity. Build orientation, printing speed, part size, layers thickness also effect on the build time for a single component or an assembly (Abdulhameed et al. 2019). Some study found how build time affect the production time and developed intelligent approaches to reduce build time (Peng 2014). From the literature it is found that layer height and filling velocity are affecting parameters for build time.

6.3 Layer thickness and printing speed

Study shows that strength of the FDM parts mainly depend on the printing speed and layer thickness. Better bonding happens between two successive layers at low printing speed with low layer thickness which revealed better tensile strength and flexural strength. With optimum printing speed of 30 mm/s, maximum tensile and flexural strength was observed (Christiyan et al. 2016). Many research studies found that the layer thickness is the most influencing parameter on the surface finish (Anthony 2004; Armillotta et al. 2018).

6.4 Number of layers (mould thickness)

Mould shell wall thickness is the most influencing parameters on the dimensional accuracy of the castings. To increase the cooling rate mould thickness should be kept lower which increases the hardness of the part produced (Garg et al. 2017). Many studies recommended the appropriate shell wall mould thickness of the cavity, for the determined accuracy of the parts. Experiments with different mould thicknesses has been performed and suggested value of mould thickness for higher dimensional accuracy has been found (Singh and Singh 2016b). By reducing the mould thickness surface hardness can be increased (J. Singh, Singh, and Singh 2020). In general number of layers affects the dimensional accuracy significantly (R. Singh et al. 2017). By increasing number of layers, the strength of part could be increased. Temperature gradient develops at the bottom of the part due to which diffusion occurs, which strengthen the part

6.5 Density of the pattern

In case of conventional investment casting dewaxing is important step, similarly during burning of the patterns density is important parameter in FDM. Many studies suggested that density of pattern does not mark on all responses. But some study suggested to use low density pattern to minimize cracking of shell. Keeping low density of pattern would produce little ash in the mould and cost effective too. Number of layer and density of patterns are influencing parameters for surface hardness of the parts (Singh and Singh 2016b).

6.6 Orientation of pattern

Surface roughness of the parts is affected by the orientation at which the part is built. The orientation of the part also affects the dimensional accuracy as well as surface finish of the patterns produced on FDM machine (Garg et al. 2017). With proper orientation, support structure required would be less due to which cost of material required will decrease. Ultimately there will be savings of fabrication time and materials. Studies suggested optimum level of orientation to improve quality and time of product.

Deposition angle (raster angle) plays a very significant role on the dimensional accuracy of the parts. Patterns produced at 90^0 orientation gives better surface finish (Pandey et al. 2003; D. Singh, Singh, and Boparai 2020). (Masood 2000) developed system with complex geometry with different layer thickness with part orientation. Generic algorithm was developed to find best orientation in order to minimize volumetric error in the component.

6.7 Baking time of mould

In the process of investment casting, mould baking time is important parameter. During baking time pattern is burnt out from the mould. Proper baking time may cause good surface finish in FDM parts. Baking time of mould is significant parameter for hardness. Optimum value was kept 40 min as baking time for proper burn out of the pattern (D. Singh et al. 2020). Surface finish is affected by drying time of primary coating. To improve the surface finish drying time of primary coating is increased (J. Singh et al. 2017)

From the literature survey various process parametric effects on the out parameter of the FDM part is found and summarized in the table3.

Table 3. Main finding parameters on quality of FDM parts reviewed from research papers

Quality measures	Main finding parameters from review
Dimensional accuracy	Layer thickness, Raster angle, air gap
Surface Roughness	Pre and Post-processing processes, Layer thickness
Mechanical properties (Strength)	Printing speed, Layer thickness
Surface Hardness	Mould thickness, Baking time, density of mould,

7. FDM process parameters optimization

In manufacturing field quality products with low cost and shorter time periods are on demand. So to fulfill these needs, process parameters must be optimized in particular machine application (Patel, Patel, and Patel 2012). In research papers different methods for optimization of process parameters are found, which are response surface methodology, Taguchi method, factorial design, Central Composite Design, etc. Optimization of processing parameters provides the correct amendments of different parameters which lead to improve the quality and strength of the parts. Many researchers found the effects of various parameters on the quality characteristics for the FDM process and suggested best setting of input factors for the proposed response parameters (Chang 2011; Garg. 2017; Singh and Singh 2016a). Many researchers found ANOVA and Taguchi method as much suitable technique to optimize process parameters on FDM.

8. Conclusion

From the literature review following conclusions are found:

- ABS is more suitable material for producing the patterns in rapid investment casting. Complex geometries could be produced with ABS material in FDM which in turn useful for investment casting.
- To produce better quality products, dimensional accuracy and surface finish of the FDM patterns should be kept higher. Process parameters which affect the dimensional accuracy and surface finish are: orientation, layer thickness, raster angle, raster width, density of pattern, air gap. With optimization techniques these process parameters can be optimized.
- There is necessity to discover the influence of various input factors like density of pattern, backing time, orientation of the work piece, layer thickness, number of layers, printing speed, etc. on the dimensional accuracy, surface finish, surface hardness and mechanical properties of the part produced. Few studies have been found on the experimental studies of various parameters optimization in rapid investment casting.

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Remotely Propelled Water Lifeguard Robot

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Abstract

Remotely propelled water lifeguard robot also known as Marine Lifeguard Robot (MLR) is designed for rescuing distressed people in water. The preeminent aim behind the construction of this robot is to make it cost effective, easily operable by remote control to navigate the distressed person at the safe place. as it will work on the principle of jet propulsion, better efficiency, sturdiness and speed can be achieved. The MLR is specifically made for organizations, having direct relation to sea or water bodies, such as rescue teams, life squad, Merchant navy, cargo ship owners, etc. for their unpredictable circumstances. The risk for both victims as well as saviours can be lowered significantly, with the help of this remotely controlled robot. Besides this, MLR will be cost-effective, light weighted, along with having capability to carry an average person who is in danger, to the safe place. The hull of the robot is made in such a way that it can sustain load up to 120kg in static condition and the range of operation can be varied by using high-tech transmitter and receiver.

Keywords – Marine lifeguard robot, Unmanned Surface Vehicle (USV), Jet propulsion, Disaster relief, Solidworks, Humanitarian aid

Nomenclature

F	buoyancy force (N)
ρ	water density (kg/cm^3)
V	volume of water displaced (cm^3)
g	gravitational acceleration (m/s^2)
CAD	computer aided design
MLR	Marine Lifeguard Robot

1. Introduction

It is a very challenging task for lifeguards to retrieve flood victims out while risking their own lives. Uneven shifting of weather and temperature, downpour occurs which becomes common problem across the world. The deadliest incident was happened in 2019, where 1900 people were dead in India which could have been saved if evacuated. To rescue these distressed people, we need whole rescue team for instance, NDRF (Natural Disaster Response force) with their boat, weather there is one person or more in danger. Inversely, in many cases, it can be seen that the NDRF team itself is put in critical conditions because of some obstacles. For instance, open drainage holes, high waves, heavy water logging. In addition, even whole NDRF boat which rescues drowning victims got drowned. Therefore, we can't afford this kind of causalities [2]. To overcome this type of constraints we are trying to make radio control (RC) vehicle called marine life guard robot which would be working based on the principle of "jet propulsion". Main objective of this project is no skilled person is required to operate the robot is also light in weight & compact in design. There are some problem specifications such as in India that people accidently fall in dams or canals while they are roaming at surrounding or doing such activities like taking selfies and having fun. Open drainage tunnels, fallen tree on the roads and choked roads, this kind of problems been usual in India so in this kind of situation NDRF team faces lots of problem and get difficulties to rescue the drowning victims. To handle and perform duties in this kind of situations we have tried to make MLR (marine life guard robot) which would be unmanned [3].

The key point of making the hull of the robot is the selection of material. There are lot of different types of material regarding this project. We have opted between two types of materials on the basis of their properties, cost, and processibility. The materials are HDPE, and foam sheet (with coating of composite fibre, resin and hardener). Here we have described properties of HDPE and foam sheet cover laying with the use of composite fibre, resin & hardener (in suitable proportion) – flexible, good chemical resistance, easy to process, tensile strength, thermal co-efficient expansion, density, good toughness even at lower temperature and also at low cost.

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1.1. Selection of material

Now here we have discussed properties of the foam sheet, composite fibre with hardener and resin which is going to be used as the parent material of this robot. Fibres used in composite manufacturing are made of glass. Such as, glass fibres. Fibre with hardener, usually replace heavy metal parts because it gives almost similar properties as heavy metals gives. Polyester is most commonly used resin bond with composites because of its balanced properties in dimensional stability, cost and ease of handling and processing. Also cost of foam sheet is very cheap and its weight is extremely low. When we apply coating of composite fibre, resin and hardener on foam sheet having specific ration of resin and hardener (2:1) then it will give good properties like hardness, floatability, bouncy, corrosive resistance and doesn't give porous effect which will be the best properties for working environment in water. After seeing all the properties of these two materials we have to analyse their processibility and its cost. As we make by our self and there is no need any type of manufacturing process. So this robot will be made by using foam sheet with composite fibre, resin and hardener as it gives required properties which is suitable for required working environment.

1.2. Working principle and Components

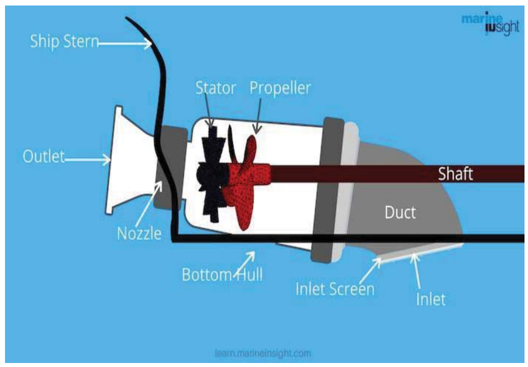


Fig.1. Illustrates the name of components and working principle of jet propulsion unit. [4]

Fig (1) shows that the what are the components uses in jet propulsion unit and placement & connection of each one. By this unit we would induce force which led to momentum of a boat by means of pressure difference. Feed water would directly inject into the main system through inlet duct which has placed at the underside of the unit. Normally single duct uses in vessels but in such cases if we need to require high power for the sake of large size vessel operations, here we can use multiple inlet duct instead of single using. Water passes to the main machinery which consist blades and stator assembly, nozzle. Blades (propeller) are powered by the impeller and the impeller is powered by the outside placed DC motor. This propeller and stator assembly connected to the motor by shaft as per shown in the figure. Shaft is rotated by the main drive shaft, connected to the motor and coupled using reinforced bearings and connectors. Injected water does not acquire high velocity energy therefore, we have to convert it into high energetic fluid. This can be achieved by producing turbulence using hydro dynamically shaped blades (propeller). When the propeller and stator assembly powered by the motor induce huge pressure difference would be generated between inlet and outlet by the means of this pressure difference and turbulence induced by the blades high energy fluid exert a force though the nozzle placed at outlet. Due to this exerted force by high energy fluid, boat would move forward by means of its reaction force. On the basis of that we can say that jet propulsion unit works on the principle of newton's third law which states that "every action has an equal and opposite reaction."
Other components from electronic side are also there, which are responsible for autonomous capabilities of robot which includes BLDC (brushless DC) motor, ESC (electronic speed controller), li-po battery, transmitter and receiver, servo, and propellers.

(a) (b) (c)

Fig.2. (a) BLDC motor (b) ESC (c) Transmitter and receiver [5]

Here we have used brushless DC motor (BLDC motor) which used as an engine of the jet propulsion unit because shaft is connected to the DC motor through shaft coupler. Brushless DC motor also known as an electronically commutated motor (EC motor). DC motor powered by DC electric power source via integrated inverter which is produce AC electronic signals to drive the motor.

Specifications of BLDC motor:

- Operating range: 3-9V, R.P.M.: 9200, No load current: 0.006A, stall torque: 35.19 gm-cm

Here we have used ESC (electronic speed controller) to get motor speed as per our requirement and to spin that shaft as per our need. ECS is directly connected to the power source or battery by using power distribution board because here we need two electronic speed controllers. ECS use to control speed of motor with frequency but not voltage. Here we can also use ECS which consist in-built battery eliminator circuit

Specifications of ESC:

- Peak current: 80A, type: brushless, battery: 2-6s, li-po, Ni-MH

Transmitters and receiver are used for make communication wirelessly over a distance. Transmitter generate radio frequency AC current antenna which is exert radio waves by radiates & navigate it. Combination of transmitter and receiver called transceiver. Which use to take place communication over a particular distance by means of radio waves generating and locating it.

Receiver which is use to catch transmitted signals by antenna as a input signal, use electronic filter to make separate wanted radio signals among all other signals which was picked up by antenna. For further processing signals must have to be at suitable level which can be accomplish by amplifies all of them. Finally, to make it readable by operator, decoding all the signals by demodulation. It is the end of communication channel

Specifications of transmitter and receiver:

- Power input: 12V DC, antenna length: 26 mm, channel: 2CH, frequency range: 2.405-2.47 Ghz

(a) (b) (c)

Fig.3. (a) Li-Po (Lithium-Polymer) battery (b) Marine propeller
(c) Servo [8]

In As power source of robot, battery is used, which is called as lithium-ion polymer (Li-po) battery. Also, it is rechargeable battery of lithium-ion technology which make out like pouch format. This sort of batteries comes out in package or pouch sue to this it is usually be in lighter as compare to cylindrical and plasmatic cell but it is also less rigid.

Specifications of Li-po battery:

- Voltage: 14.8V, constant discharge: 40C, maximum discharge: 50C (10sec), dimension: 127 x 44 x 40 (L x W x H) (mm)

Propeller which is kind of hydrodynamically shaped blades three or more than that which is placed at the end of the shaft. Propeller produce thrust from powered rotational motion by creating a pressure difference between the forward and rear surfaces of the air foil-shaped blade.

To get automatically movements with parts of machine with precision of particular velocity and acceleration we can be use servos, servo motors. Servos are mainly act as linear or rotary actuators. It is also called as electronic actuators.

Specifications of servo:

- Operating range: 4.8~6c (VDC), stall torque: 10 kg-cm, speed: 0.22 sec/60 degree, rotation: 180 degree

1.3. Water cooling system

Fig.4. Water cooling system [11]

Heat used to be generated due to physically connected movement between two mechanical components, need to dissipate this unwanted generated heat, we can be accomplished this by using colling system. Here we are using water cooling system which is use widely to keep ECS and other components comparatively cool. The components are wrapped with aluminum tubing coils which is connected to the flexible tubing by means of water pick up from bottom of the hull. Water suck by that flexible tubing and provide conductive cooling to components. First of all, we have lubricated main propeller which would keep cool by dissipate heat which is produce due to friction between shaft and blades.

2. Design and analysis

For the analysis purpose we have made the CAD design of the robot in the 3d cad modelling software called solidworks and for analysis we have used Ansys software. Solidworks is the 3d modelling CAD software, used by many industries such as automobile, product designing, etc., owned by company named Dassault System. Ansys is the software which is used to analysis the designed product. Many MNC's are used this software at industrial level for their analysis purpose.

(a) (b) (c)

Fig.5. (a) 2d design of hull (b) 3d cad design of hull (c) Simulation of hull

Fig.6. 3d design of motor stand

Fig.5 (a) and (b) shows the design and dimensions of hull which is designed using solidworks software. Which consists of slots which are used for connection of all electronic parts and two provisions for jet propulsion unit. Fig.5 (c) shows the simulation analysis of hull which shows the maximum pressurized area in water. Key point of design is the stability and flexibility of hull. Design should be such that hull can withstand the sudden impact of waves.

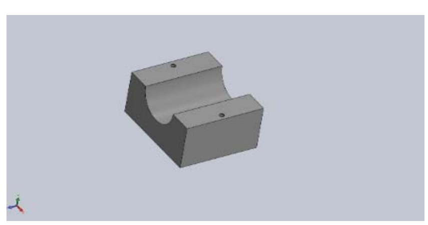
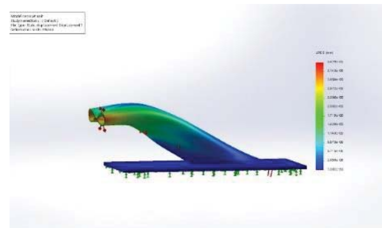


Fig.6 stand of motor

Fig.6 shows the stand for motor. Purpose of making this stand is that the shaft which is connected to the motor shaft by using coupler must be straight with the propeller off the jet propulsion unit and it will rigidly be coupled with clamp to avoid deflection while in action.

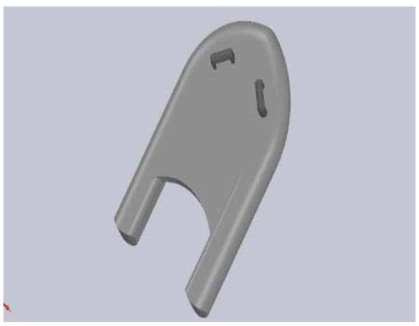
(a)



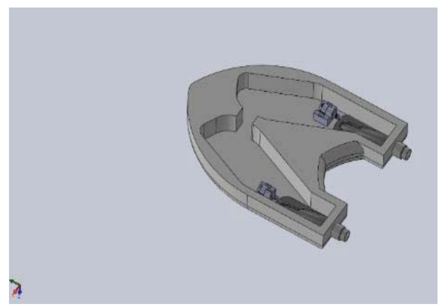
(b)

Fig.7. (a) 3d design of jet propulsion unit (b) Simulation of jet propulsion unit

Fig.7 (a) and (b) shows the design and analysis of jet propulsion unit which is going to be 3d printed. It consists of a base which is going to mounted on the base of the hull, one manifold having inlet at base and outlet at upside where nozzle and propellers are going to mounted at the outside of the hull. Fig.14 shows the flow simulation of manifold of jet unit for experimental purpose.



(a)



(b)

Fig.8. (a) Cover of hull (b) Assembly of hull and jet propulsion unit

Fig.8 (a) and (b) shows the upper cover of hull which consists of two stand which are mounted on the top side of the cover for holding purpose for drowning victim as they can hold it easily and they could be saved. fig.16 shows the assembly of hull, motor and jet propulsion unit. To reduce pressure energy at the outlet and reversely to increase velocity at out let two nozzles is connected with the two jet propulsion units respectively. Motor is mounted on the stand rigidly to avoid deflection of shaft which is connected to the motor shaft using coupler through jet propulsion unit having propeller mounted on the other side. When motor rotates, shaft is also rotate and therefore propellers rotate and start sucking water from the inlet of the propulsion unit and throw it with high velocity to the outlet of jet and because of this, propulsive force is generated and vehicle goes in forward direction.

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2.1. Block diagram

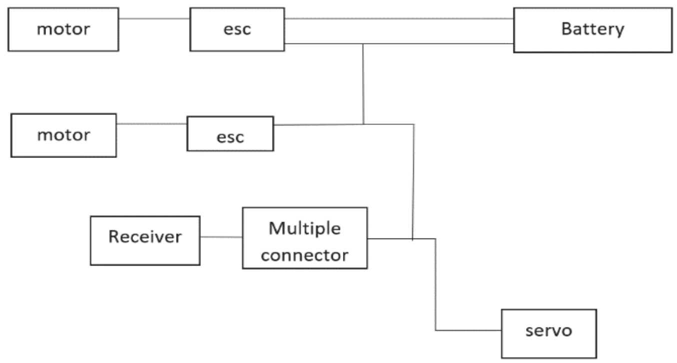

Fig.9. Illustrates the Block Diagram of connection of the electronic parts [12]

Fig.9 shows the working block diagram of the connection of all the electronics. Two jet propulsion unit therefore two BLDC motors are used for propulsion system. Two ESC (electronic speed controller) are used for each motor to control the speed. Servo is connected to the battery through multiple connector receiver is also connected to receive signals form transmitter and one rechargeable li-po battery is connected to the system as power supply.

3. Calculation of load carrying capacity

3.1. Principle of calculation

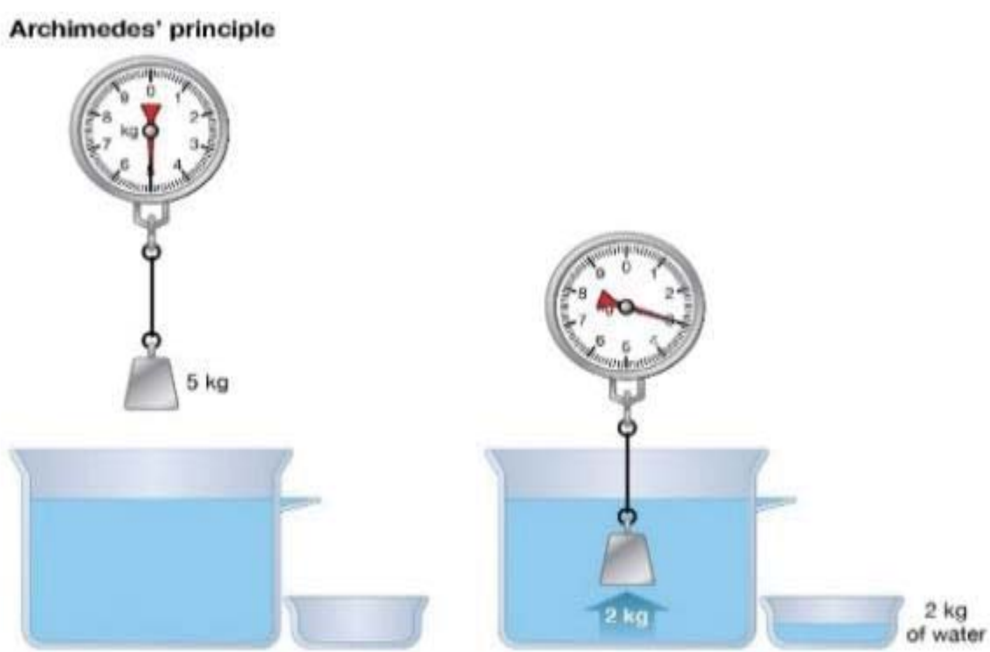

Fig.10. Illustrates the Archimedes principle. [13]

Here calculation of buoyancy and capacity of boat to hold people on it play important role. Capacity of boat can be determined by using the principle of Archimedes' which states that Archimedes' principle states that the upward buoyant force that is exerted on a body immersed in a fluid, whether fully or partially, is equal to the weight of the fluid that the body displaces.

3.2. Mathematical calculation

$F = \rho v g$ ………………… **(1)** [14]

- F = Buoyancy force, N,
- ρ = water density, kg/cm^3,
- V = volume of water displaced, cm^3,
- g = gravitational acceleration (m/s^2)

Considering static position of hull,

(a=g) ……………… **(2)**

From equation (1),

$F = \rho v g$

Ma = $\frac{m}{v}$ vg

M = $\frac{m}{v}$ v (from equation (2)

M = ρ v where, ($\rho = \frac{m}{v}$)

V = M/ρ ……………………. (3)

M = total weight (kg)

Now, from dimensions of hull,

Length (L) = 90 cm, Width (W) = 70 cm,

Height (H) = 20 cm

w = 5 kg (weight of hull)

Area of hull, (A) = W*L (cm^2)

Now, considering full loaded condition

$\frac{volume\ of\ water\ displaced}{area\ of\ hull}$, $\frac{cm^3}{cm^2}$ = buoyancy, (cm)

$\frac{x}{6300}$ = 20, (cm)

X = 126000 cm^3 (volume of water displaced)

Now,

ρ = 0.001, kg/cm^3

From equation (2)

M = v * ρ

M = 0.001 * 126000 = 126, (kg) ………………… **(4)**

Now, subtracting weight of hull (w) from equation (3) we get max. load carrying capacity of robot,

M – w = 126 – 5 = 120 (kg)

here 120 kgs will be the max. load can be sustained by boat. Now considering 80 kgs is the average person weight than factor of safety can be determined as

FOS (Factor of safety) = max. stress / working stress

= 120/80

= 1.5

4. Results and discussion

Implementation of coating of composite fibre with appropriate mixture of resin and hardener having ratio of (2:1) respectively.

(a)

(b)

Fig.11. (a) and (b) coating of composite fibre with resin and hardener on foam sheet


(a)


(b)

Fig.12. (a) final product (b) hull is floating on water

Fig.12 (a) shows the final product after coating. Fig (b) shows that final product can easily float on the water surface.

4.1. Costing estimation

Following is the cost estimation which includes cost of various components and other necessary details.

Table of cost estimation

Sr. No.	Description	Cost (Rs.)
1	Composite fibre (Rs. 150 per kg)	1000
2	Resin (Rs. 150 per kg)	300
3	Hardener (Rs. 130 per kg)	250
4	Foam sheet (60 Rs. Per sheet)	580
5	BLDC Motor (Rs.400 per motor)	800
6	ESC (Rs.448 per piece)	896
7	Li-po battery	2000
8	Transmitter	600
9	Receiver	150
10	Servo	431
11	Propeller (Rs. 1100 per piece)	2200
12	**Total**	**9207/-**

Table shows the cost estimation of robot which is approximately 9000 to 10,000/- Rs. where existing water rescue product price is nearly $10,000 (cost of E.M.I.L.Y.) which is around 7 lakhs. in INR.

4.2. Conclusion

- It is very economical and fairly simple to operate.
- Performance and handling of the robot is much batter by using jet propulsion principle.
- It can be used by any organization for emergency rescue operation as it is light in weight, easy to operate having low cost.

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Review on Gas Tungsten Arc Welding of Stainless Steel and Mild Steel Plates

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Abstract

Tungsten arc welded plates are commonly used in industries. The Welding of dissimilar metals is particularly useful in structural applications. However, welding such plates is difficult due to the loss of carbon from mild steel and the precipitation of chromium in stainless steel during the welding process. TIG welding is the best process for controlling these issues that arise during welding on base metals. This paper review TIG welding of Stainless steel and mild steel plates.

Keywords: TIG welding, Dissimilar Metal Welding, Carbon Migration

1. Introduction

Welding is a process that involves applying heat and pressure to two or more parts to form a permanent joint. The process produces a mixture of materials by reheating them before they re-crystallize temperature with or without the inclusion of filler material, and with or without pressure. Welding is a method of joining metals permanently.TIG welding is a form of welding that uses a tungsten electrode that is commonly used in modern industries to join materials that are identical or dissimilar. We can easily join by using the TIG welding process. Nuclear reactors, Construction, thermal power plants, vessels, and heat exchangers are all examples of civil engineering, as well as a range of industrial applications, all use stainless steel and mild steel plants.

Gas tungsten arc welding (GTAW), otherwise called tungsten inert gas (TIG) welding, is a sort of a bend welding measure that utilizes a non-consumable tungsten anode to create the weld. The weld region and anode are resistant to oxidation or other barometric pollution by an idle protecting gas (argon or helium). Filler metal is by and large utilized, however a few welds, alluded to as autogenous welds, or combination welds don't need it. At the point when helium is utilized, this is frequently alluded to as heli-arc welding [1].

GTAW welding thin stainless steel and non-ferrous metals like aluminum, magnesium, and copper alloys are a specialty. This approach provides rival methods like welding techniques include shielded metal arc welding and gas metal arc welding. Give you more control over your weld, resulting in quicker, and higher-quality welds. GTAW, on the other hand, is considerably more complex and difficult to track than most other welding methods, as well as significantly slower. Plasma arc welding is a similar method that employs a slightly distinct welding torch to produce a larger weld, extra centered arc welded and is often automated as a consequence [2].

Since it affects electrode burn-off rate, fusion depth, and weldment geometry, welding current is the most important variable in the arc welding process. Weld bead shape, welding speed, and weld efficiency are all affected by current. Since DC on electrode negative (DCEN) (straight polarity) produces greater results, Weld penetration depth and travel speed are greater on the electrode positive (DCEP), and it is used in the majority of GTAW welds (reverse polarity). Reverse polarity allows the electrode tip to heat up rapidly and degrade in gas tungsten. Since the anode heats up faster than the cathode. A higher current in gas tungsten arc welding can cause spatter and damage to the workpiece. Again, in gas tungsten arc welding, a lower current setting causes the filler wire to stick. To deposit an equal amount of filling content, high temperatures must be applied for long periods. So greater heat-affected areas are often seen for lower welding current. The voltage is adjusted in fixed current mode to keep the arc current steady [3,4]. Generally, we achieved defect-free joints by tungsten inert gas welding, as compared to other welding processes. Give you more control over your weld, resulting in quicker, and higher-quality welds. GTAW, on the other hand, is considerably more complex and difficult to track than most other welding methods, as well as significantly slower. Filler metal is by and large utilized, however a few welds, alluded to as autogenous welds, or combination welds don't need it. This approach provides rival methods like welding techniques include shielded metal arc welding and gas metal arc welding.

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2. Working Principal of TIG Welding

It operates in the same way as arc welding does between the tungsten and the work object, a powerful arc is formed. Heat is created by the arc, which is used to fuse the sample. Shielding gas is often used to stop oxidation of the weld surface [5].

The gas is ionized as it is supplied by the tank, an arc forms between the electrode and the work object as a result. Heat is produced, causing the Welding of base metal and filler rod to fail and the filler metal to fall onto the heated joint. One of the workpiece is formed by a DC source with positive polarity. The negative polarity is applied to the electrodes. The power source may be a negative electrode and a continuous voltage AC or DC power source that produces a smooth metal transfer and a steady arc with minimal splatter all over the existing spectrum [6].

Power sources for welding, high-frequency unit, and cables are the main components of the TIG operation. To complete the TIG welding process, we required a welding torch, tungsten electrode, and filler metals. We also needed an inner gas cylinder, a pressure regulator, and a flow meter to get the best welding efficiency. Inert gas is commonly used to protect against contamination of welded joints and ambient gases. TIG welding often necessitates the use of cooling water to keep the device cold, as well as a gas valve [7].

2.1. Mechanism

The weld is made with a non-consumable Tungsten electrode. Electrodes with a diameter of 0.5 mm to 6.4 mm and a length of 150 mm to 200 mm are widely available. Depending on whether they are connected to a positive or negative terminal, electrodes have different current-carrying capacities. Thorium and zirconium are used to keep the electrode from melting since the arc length varies, to hold the current steady, a constant current power source is used. The welding torch receives power from the power source and delivers it to the electrode, which is housed within the torch holder. For Aluminum and Magnesium, an AC power supply is usually favored because the cleaning action of AC eliminates oxides and enhances joint consistency. A constant-current welding power supply creates an electrical arc between the tungsten electrode and the workpiece.

Noble gas, typically Argon or Helium or a combination of both, the tungsten electrode, and thus the welding zone, is shielded from the ambient air. Temperatures of up to 20,000°C are formed, which are used to join two separate materials. The electrical arc is fed with filler metal either manually or automatically. Depending on the type of fabric or alloy we're welding, the filler rod we use is critical [8].

2.2. TIG Welding Process Parameters

The following operating variables influence the weld bead geometry, penetration depth, and overall weld efficiency. Tungsten inert gas welding produces excellent weld efficiency, but welding parameters and joint geometry have a significant impact on weld deposition rate. For a good and best outcome, proper process execution and control of a large number of parameters are critical. Normally, various combinations of welding parameters and joint geometries are used to create a welded joint.

2.2.1 Welding Current

The most important variable in the arc welding technique welding current regulates the level of electrode decomposition, fusion depth, and weldments geometry. Current has a direct impact on a welded bead form, welding weld, and pace efficiency. Since DC on the electrode negative (DCEN) (straight polarity) achieves the greater depth of penetration and movement speed of the weld DC on electrode positive (DCEP), it is used in the majority of GTAW welds (reverse polarity). Furthermore, since the anode is more heated than the cathode in a gas tungsten discharge, polarity inversion causes the electrode tip to heats up quickly and degrades. In GTA welding, a higher current will cause splatter and damage to the workpiece. Again, in GTA welding, a lower current setting causes the filler wire to adhere. Since high temperatures must be applied for long-term limits for deposits and a similar quantity of filling products, lower welding current also results in larger heat-affected areas. The voltage is varied in fixed current mode to maintain a steady arc current [9].

2.2.2 Welding Voltage

The electrical potential between the welding wire's tip and the ground, as a result, the molten weld pool's seeming. Depending on the GTA welding voltage, welding equipment is often set or adjustable. It defines the fusion zone's shape as well as the reinforcement with welds. Arc initiation is aided by a high initial voltage and permits for a superior working tip distance series. It does, however, generate larger, Low welding voltages that produce flatter, less deeply penetrating welds; At maximum arc voltage, the penetration depth is greatest, on the other hand, high welding voltage causes significant variations in welding efficiency [10].

2.2.3 Welding Speed

The rate at which the electrode is moved along the seam or the rate is increased at which a job done with an electrode travels along the seam, determines welding speed [11]. Weld Travel Speed is measured in millimeters per minute of electrode/arc travel. Welding speed is an essential factor in GTAW welding. Accelerating for a given current and voltage, the welding speed has the effect of reducing the warmth input. Since they're connected to the current, the electromagnetic force is unaffected by welding speed and hence the arc strain. As weld speed increases, the region of the weld cross-section shrinks. The D/W ratio, including penetration depth (D) and weld width (W), has only a small impact on travel speed. These findings indicate that the travel speed has no impact on the processes involved in the creation of the weld pool, rather than the amount of material that has melted as a function of current, material form, and other variables, welding speeds vary from 100 to 500 mm per minute and thickness of the plate [12].

2.2.4 Shielding Gases

There are numerous shielding gas applications in the GTAW process. Since it protects the weldment from atmospheric pollution, shielding gas is very necessary for the form of tungsten inert gas welding. The presence of oxygen and hydrogen in the atmosphere causes our weldments to heat up, which is why we use shielding gas as a protective layer on the weldments. Argon, helium, and argon + helium are also Gases that are used as shielding agents.

Helium is recommended for welding thick aluminum workpieces since it has a higher ionization potential than other high-conductive materials like copper alloys than argon, requiring arc initiation and maintenance at a higher voltage, but with more heat output [13, 14].

2.2.5 Filler Metal

Filler metals, which have a content creation in the same vein as the parent material, are commonly used for plate thicknesses greater than 2 mm. Filler metal is usually applied cold from a roll or a loop in programmed frameworks and ranges in thickness from 1.6 to 3.2 mm. Austenitic steels come in a variety of forms, but not all of them are austenitic hardened steels that are welded without the use of filler metal or additional heat treatment regularly. To achieve adequate erosion resistance of the weld, the vast majority of very austenitic mixtures necessitate the use of filler metal. Frequently, the weld metal is in a position to meet the reinforced base material's fundamental yield and durability requirements. The welds' malleability isn't quite as good as base metal, but they're still bendable. Filler metals with low carbon grades (L-grades) are commonly used in consumption-safe assistance. The upper metals of carbon filler will stimulate higher-temperature output administration for high-temperature administration. A large number of the 300 filler metals have had their structures changed to ensure that the cement with a sufficient total of ferrite to avoid hot breaking during hardening. This takes into account higher warmth sources of information and, as a result, greater welding speeds. The existence of a specific volume of ferrite denotes that the Welds have a ferromagnetic property. Welding should be done with lower heat inputs for compounds that are set fully or nearly completely austenitic. An express ferrite weld metal is appealing for certain applications, and convinced filler metals are shipped for that determination. The most popular filler metal used in most 300 arrangement tempered sheets of steel is coordinating with filler metal [15, 16].

2.3. Advantages, limitations and applications of Gas Tungsten Arc welding

Advantages:

- TIG welding necessitates the use of a tungsten electrode that is not consumable.
- Filler metal is applied by hand when necessary.
- To secure the weld and the tungsten, shielding gas is used.
- Welds a greater number of metals than any other process [17].

Limitations:

- TIG fusing is a labour-intensive process. They are more time-consuming than the other welding methods.
- TIG welding is more difficult because it needs highly qualified and experienced personnel.
- Health and safety concerns Welders are exposed to high levels of light, which can cause eye damage.
- The initial cost of TIG welding is extremely high [17].
- TIG welding is more difficult because it require costly equipment.

Applications:

- TIG welding is reasonable in steel welding situations where quality and visual part of weld crease are the principal significant issue With the assistance of TIG welding we can join a wide range of steel grades.
- General applications for creases that need a great visual look.
- Metal furniture, machine building, bikes, and so forth. The chemical industry needs smooth weld profiles. Lines, tanks, and so forth Aviation and flying corps use TIG welding for its unwavering quality.
- Thin sheet industry, Automotive and vehicle industry, transport industry, and so on repair welding of all sort of steel.
- Machinery, support, and so on X-beam quality root passes.

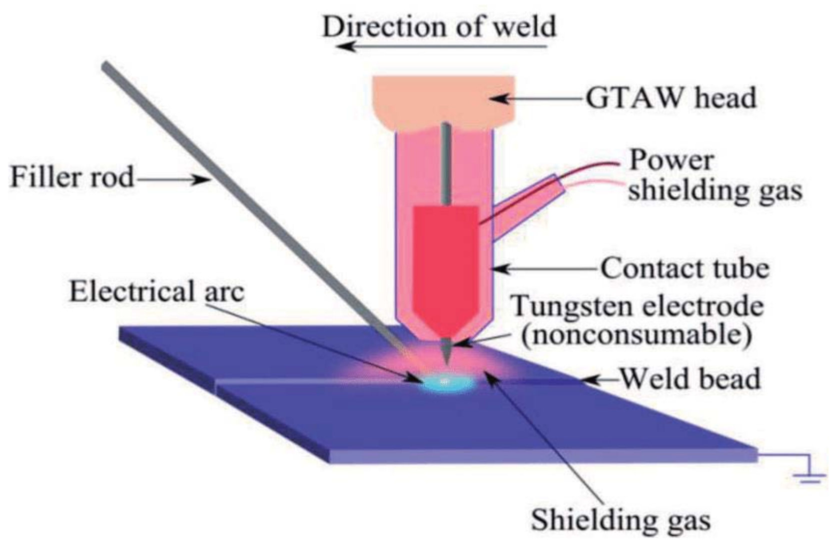


Fig. 1: TIG Welding [18]

3. Dissimilar Metal Welding

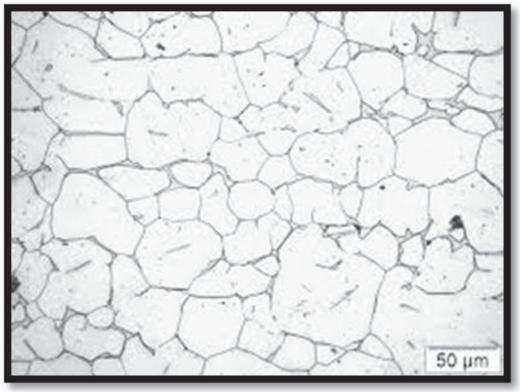
This is a method of joining two metals that have different chemical or mechanical properties and aren't a good match. Since it consists of more than two different metals, such as aluminum and steel, the word can be a little confusing at times. Infect, two metals of the same name are often welded together, but if they need different core properties, they are referred to as dissimilar metals. You could weld two steel metals together, for example, they will, however, vary enough to be considered dissimilar.

This Welding establishes a solid, long-lasting bond between the two metals, resulting in a single finished product. In the section below, we go through the procedure in greater detail. This welding method functions almost identically to that of joining two similar metals together using a beam that is precisely centered on the metals; you melt each of the metals together until they form a single linked joint. If the two metals aren't welded differently, such as if you're using two austenitic sheets of steel, as we discussed earlier, the two will frequently come together seamlessly. Different Factors that should consider are:-

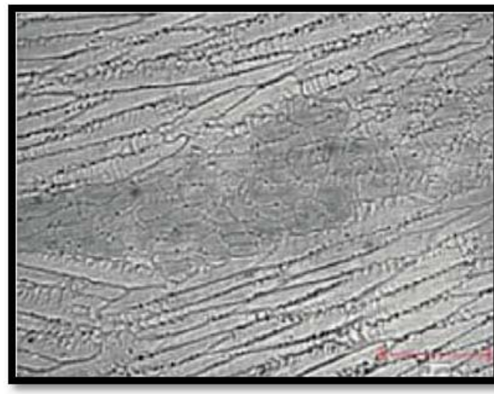
- Solubility – This is the tendency of a metal to dissolve in a solvent. Both metals must be able to dissolve in each other.
- Intermetallic compounds – During the welding process and exhibition metallic bonding, these will be formed in the conversion region.
- Weldability – Dependent on the solubility of two metals and their Intermetallic compounds.
- Thermal expansion –Temperature rise determines how much the form of your metals changes.
- Melting rates –The stage at which metal begins to melt.
- Corrosion –Corrosion is characterized as the occurrence of corrosion when two metals have different electrochemical scales.
- End–service conditions – Regardless of the circumstances under which your dissimilar metals will be used.

The GTAW (TIG) welding measure was first evolved in quite a while in the mid-1940by Russell Meredith of Northrop Aircraft Corporation. Around then Northrop required an approach to weld aluminium and magnesium and current welding measures were not satisfactory to weld these combinations. President Roosevelt, in a letter to Winston Churchill, would later flaunt about the disclosure of new welding strategies that empowered America to assemble ships with a speed unparalleled throughout the entire existence of shipbuilding. TIG or GTAW (Heli arc) was created to join light amalgams utilized in airframe producing, explicitly, Magnesium. The TIG cycle gave a steady, reasonable approach to rapidly accomplish top-notch welds [19].

Stainless steel is a category of iron-based alloys with at least 11% chromium, a composition that prevents rusting and provides heat resistance. Stainless steel contains nitrogen, aluminium, silicon, sulphur, titanium, nickel, copper, selenium, niobium, and molybdenum, among other elements (ranging from 0.03 percent to greater than 1.00 percent) [20, 21].



(a)



(b)

Fig. 2: (a) 304 L Stainless Steel microstructure [22] and (b) Microstructure of 304 L Stainless Steel by TIG Welding [23].

Table 1:- Effect of TIG welding on various Stainless steel-grades

Reference No.	Materials	Type of welding	Parameters	Outcomes
[24]	SS 304	TIG	308 stainless steel filler wire	HAZ has a dendritic structure and a coarse-grained structure. Tensile power, yield strength, and elongation are all 1800 MPa, 75 MPa, and 25%,correspondingly.
[25]	SS 316L	TIG	Ar Gas with H2 [H2 concentrations of 0 percent, 1.5 percent, and 5%]	1.5 percent H–Ar has a higher tensile power. With increasing H2 content, penetration depth and weld bead width increase.
[26]	SS 304L	TIG	Multipass TIG 304 SS filler metal	The welds had a dendritic microstructure, which is -ferrite. The optimum hardness value is obtained for three pass specimens.

Fig. 3: TIG welded plates

Table 2:- Chemical composition of grade 304 and CRI

Element	ASTM A 240 GRADE 304	IS 513GRADE-CR1
Carbon	0.048	0.042
Sulphur	0.014	0.004
Phosphorous	0.030	0.020
Manganese	1.090	0.189
Silicon	0.406	-
Chromium	19.12	-
Nickel	8.01	-
Nitrogen	0.052	-

When used on stainless steels and mild steels, the key benefits of this process are often summarised as follows:

1. A localized heat source that leads to a small fusion zone.
2. 2. A small welding pool with a very stable arc and a calm environment. Spatter isn't a problem, and the oxidation method doesn't require any flux.As a result of the removal of residues, any final cleaning process is greatly simplified.
3. A high level of metallurgical efficiency, with a focus on penetration and weld form in all positions.
4. Welds that are sound and pore-free.
5. Electrode wear resistance is extremely poor[27].

To join mild steel and a stainless steel standard, TIG welding was used. Elasticity welded joint weakening, hardness, and curve analysis were all looked at. The weld properties are largely determined by the collection of various evaluations of processed steel used for welding. For S.S. and MS plate joints welding with tungsten inert gas is the best option. In the welding industry, we can see there isn't anything deformity found because of welding like porosity, breaks, and so on likewise twist test demonstrated the best outcome for this work. The result was fulfilled and clears a pondered welding under twist load. Since the deficiency of Cr from S.S. during TIG welding is extremely low, it resists erosion in the field. Furthermore, welding is performed in an inactive environment to protect the weld from hydrogen and other environmental hazards. According to the article, the strength of various metals welded by TIG welding is incredible. Hardness esteem at the motivation behind filler metal is at an all-time high, which simply the result of form exploration is progressing. When we add up all of the test results, we find that TIG welding on similar metal plates produces the best results [1].

Differing welding was done with SS-316 and MS-E350BR, both of which were ostensibly 8 mm thick. Tables 3 and 4 show the compound structures of the SS-316 and MS-E350BR combinations, respectively.

Table 3:- Chemical composition of SS- 316.

%	C	Mn	Si	P	S	Cr	Mo	Ni	N
SS 316	0.08	2.0	0.75	0.045	0.03	18.0	3.0	14.0	0.10

Table 4- Chemical composition of E350BR.

%	C	Mn	S	P	Si	Nb +V+Ti	N	CE Value
E 350BR	0.20	1.50	0.045	0.045	0.45	0.25	-	0.42

Disparate metal SS 316 and E350BR are welded by TIG welding. On a variety of comparable and dissimilar materials, there has been some work on TIG welding with gases. Done to consider and advance the welding yield such as elasticity, the tensile strength of weld joints, and so on shifting the information boundaries such as welding current, gas stream rate, welding speed, and so on.

Karpagaraj et al. [30] suggested that Drop geometry, reinforcements, and weld depositions are of particular concern to the majority of the investigators. Micro-hardness, impact strength, and corrosion studies are among the other outcomes that need further focus. New and hybrid techniques can also allow for improved optimization and calculation. Rattana Borrisutthekula et al. [31] concluded that at a given heat input, increasing welding speed or current did not affect the welding width and thickness of the intermetallic reaction sheet. Wider welds and narrower welding windows resulted from increasing the arc length, however, it was not discovered to be a factor in the height and width variance of the Layer of intermetallic reaction. The strength of the intermetallic reaction layer is affected by changes in welding speed and arc length. K.C. Ganesh et al. [32] suggested that since most recent studies on activated TIG welded joints have based on it is dynamics of molten weld pools, this study provides insight into the thermo-mechanical behavior of A-TIG welded joints compared to MP TIG-welded joints. The mechanical-thermal behavior of Welded joints made of 316LN stainless steel was investigated by the MP TIG and A-TIG fusing processes. Himanshu Garg et al. [33] reviewed the TIG and A-TIG joining methods. Estimates for TIG and A-TIG welding procedure variables, as well as Microstructure, mechanical, penetration depth, and weld bead consistency are examples of weld outcomes, have also been given. In comparison to TIG welding, activated TIG welding has greater hardness and mechanical properties. The microstructure, mechanical properties, and comparisons between the two weld developments are all extensively explored, as are the weld characteristics of stainless steel in TIG and A-TIG. A-TIG welding possesses a higher weld penetration than conventional TIG welding, resulting in different welding properties. The effects of depth penetration and the ratio of depth to width differed as different fluxes were used.
A. Karpagaraj et al. [34] identifies the most widely used optimization techniques for the GTAW process. Each GTAW procedure parameter's contribution is recognized. The graph shows that the most important parameters in GTAW are WC and WS. Peak current and back current in the pulsed GTAW action are the most energetic limits. To measure the GTAW process parameters, hybrid techniques were introduced. Bead geometry, reinforcements, and weld depositions are of particular concern to the majority of the researchers. Micro toughness, impact strength, and corrosion studies are some of the other outcomes that need further focus. Other GTAW parameters will be studied in the future, and the results will be interesting. Techniques that are modern or hybrid. According to YasuoSuga et al. [35], sudden changes occur in welding conditions, similar to root hole, welding speed then on, the welding framework can optimally control the welding conditions. The built framework is tried and situated to be successful for entrance control in programmed butt welding of slight low-carbon steel plates. A smart welding robot framework with vision sensors that notice the structure and measurements of the weld liquid pool, including length, width, and the region was built. A versatile framework utilizing Artificial Neural networks was proposed. It's an Input layer of six units for length, width, region, welding speed, welding current, and root hole of welding line, a yield layer of seven units that show change of welding current, and a secret layer of eight units. Naishadh P. Patel et al. [36] reviewed Effect of Activated Fluxes on Weld Penetration and Mechanism Responsible for Deeper Penetration of Stainless Steels.

4. Summary:-

• In the arc welding process of gas tungsten arc welding, also known as tungsten noble gas welding, a non-consumable tungsten electrode is used to supply the weld. As compared to rival methods like shielded metal arc welding and gas metal arc welding, this method is superior, the process allows for more control over the weld, resulting in cleaner, higher-quality joints.
• Low-carbon steel plates up to 6 mm thick are usually joined using TIG welding.TIG welding produces a more accurate and safer low-carbon steel weld than other arc welding techniques such as manual arc welding or metal noble gas joining. Low-carbon steel is a ductile metal that can be machined quickly. TIG welding machines are available in two current ratings: high and low.TIG welding has a current range of 150 A to 350 A, which is ideal for welding thick low-carbon steel plates. We can see that there are no defects found due to welding, such as porosity, cracks, and so on. TIG welding creates a stronger bond between metals that aren't compatible.

5. Conclusion:-

TIG welding effect on stainless and mild steel plates was studied in this paper, with various welding speeds, welding current, voltage, and other parameters and others influencing the results. Mild steel and stainless steel plates were joined using the TIG welding method. In which defects such as porosity and cracks cannot be detected using this welding technique. TIG welding of stainless steel and mild steel produces superior properties as compared to other welding processes.

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Review on Effect of Heat Treatment on Properties of AA 2024

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Abstract

This paper reviews the effect of heat treatment on properties (Ultimate tensile strength, Hardness, Yield strength, elongation and modulus of elasticity) of AA 2024 alloy (Aluminum – Copper) under different heat treated conditions O, T4, T6. This paper involves the annealing, solution zing and the ageing process of AA 2024 alloy. This paper compares initial properties and property change after heat treatment is made to study effect of different heat treatment on material properties. In this paper the properties and application of AA 2024 alloy is presented. Also the hardness change in different quenching medium studied. The mechanism of solution zing and age hardening process is also studied in this paper. Finally conclude that there is increase in mechanical of AA 2024 alloy after performing heat treatment process.

Keywords: Heat treatment, annealing, precipitation hardening, properties, application, mechanism, microstructure

1. Introduction

There are two group of aluminium alloy: One which cannot be heat treated, and other which can heat treated. The heat treatable alloy can be hardened by the addition of certain alloying elements, such as copper, zinc, magnesium and silicon. Because of solubility and precipitation forming ability of these elements alloys can be heat treated. The process heat treatment of this alloy is consists of heating the solution above its Solidus line followed by quenching in water or other liquid solution like (oil, brine solution, polymeric solution) or aging [1].
Since 1930's the aluminum alloys are major elements use in aircraft industry because of its light weight, strength and excellent corrosion resistance [2]. AA2024 is one of the most widely used material in air craft industry aluminum 2024 is use in the airplane fuselage, the wing panes of air craft, the rudder, the exhaust pipes of air crafts, the door and floors of air plane and other aeronautic components, the seats, the engine turbines, and the cockpit instrumentation of air craft [3].
The heat treatment of metal by age hardening is possible for an alloy that show the decreasing solid solubility of at least one alloying element with decreasing temperature [4]. These alloys undergo the precipitation hardening. During the precipitation hardening process different precipitates can be obtained depending on the type of alloying element the alloy possess. This process will influence and produce different mechanical properties [5]. By using the precipitates line chart this precipitates are positioned on phase diagram, and the phases that are stable can be detected. So to obtain the good mechanical properties appropriate fabrication process should be chosen. Also, one needs to consider aging time and temperature, occurrence of deformation and the whole fabrication process to obtain best properties [6]. So the solution treatment and ageing give positive effect on the properties of material.

1.1. Classification of aluminum alloy based on heat treatment

1. Heat treatable aluminium alloy. : 2xxx, 6xxx, 7xxx
2. Non heat treatable aluminium alloy : 1xxx,3xxx,4xxx,5xxx,8xxx [7]

Temper designation
First the basic designation is based on operation performed on the alloy.
1.F, As-Fabricated: This process is applied to product which are shaped by cold working, hot working, or casting processes in which there is no special control over thermal conditions and strain hardening is required [8].
2. O, Annealed: This process is applied to wrought product which are annealed to obtain lowest-strength temper and to cast products that are re - annealed to improve ductility and dimensional stability of product [8].
3. H, Strain-Hardened (Wrought Products only): This operation shows the products which are strengthened by strain hardening, with or without supplementary thermal treatment to produce some reduction in strength [8].

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The designation of H is:
H1: only strain hardening.
H2: Strain hardening and partial annealed.
H3: Strain hardened and stabilized [9].
4. W, Solution Heat-Treated: This operation is an unstable temper operation which is only applicable to alloys whose strength is naturally changes at room temperature over a duration of months or even years after solution heat treatment [8].
5. T, Solution Heat-Treated: T is applied to alloys whose strength is stable within a few weeks of solution heat treatment [8].

T, Solution Heat treated – designation
T1 – partial solution treatment and natural aging.
T2 – Partial solution treatment, cold worked and natural aging.
T3 – Solution treatment, cold worked and natural aging.
T4 – Solution treatment and natural aging.
T5 – Partial solution treatment and artificial aging.
T6 – Solution treatment and artificial aging.
T7 – Solution treatment and Stabilized or over-aged.
T8 - Solution treatment, cold worked and artificially aged.
T9 - Solution treatment, artificially aged and cold worked.
T10 – Partial solution treatment, cold worked and artificially aged [10].

1.2. Heat treatment

Annealing and precipitation hardening is heat treatment processes for implementation of properties of heat treatable aluminium alloy [11].
Annealing: Annealing is a process which decrease the strength and hardness while increase the ductility. Annealing can used for both heat treatable and non heat treatable aluminium alloy with both grades of wrought and cast alloys. If the cold worked aluminum alloy is heated at sufficiently high temperature for long time then annealing process divided into three parts: 1. Recovery: During recovery the stresses which are produced by cold work are reduced, with decrease in strength and increase in ductility. 2. Recrystallization: During recrystallization the new undeformed nuclei form and grow until they react with each other to form a new recrystalized grain structure. 3. Grain growth: The increase in grain size of new formed recrystalized grain is grain growth process [12].
Quenching: Quenching is a process when a metal is subject to heat at a high temperature and then follow by a rapid cooling as fast as possible by immersing the heated metal in a relatively colder liquid such as oil, water, polymeric solution, air. This process increases alloy’s strength and corrosion resistance. The alloy’s properties are determined by the constituents present in alloy as well as its properties like its thickness and cooling rate when the alloy is quenched which depends on the type of quenching medium and temperature.
Maximum corrosion resistance can be obtained from quenching in cold water which is implemented on products manufactured by tube sheet, extrusions. Slower quenching mediums such as boiling water is implemented on large or forgings sections. Lower quenching rate has a more homogeneous cooling rate and it produces a less distorted and cracked product which usually occur from uneven cooling. The quenching medium temperature does not affect the corrosion resistance; it is observe that the corrosion resistance is less in thick or heavy parts than it is in thin parts [13].
The metal obtain high strength through the rapid cooling from the high-temperature solution followed by aging treatment. But the rapid cooling from high temperature lead to undesirable residual stresses [14]. When the heated parts are quench the quenching rate at surface of metal and center of metal produce thermal gradient which will result in inhomogeneous plastic deformation [15]. It has been noted that the residual stresses have negative effects on parts properties which cause distortion and dimensional variation result in premature failure [16]. To increase lifetime it is required to remove all the residual stresses from metal to obtain dimensional accuracy.
The alloy’s properties are determined by the constituents present in alloy as well as its properties like its thickness and cooling rate when the alloy is quenched which depends on the type of quenching medium and temperature. During recovery the stresses which are produced by cold work are reduced, with decrease in strength and increase in ductility. 2. Recrystallization: During recrystallization the new undeformed nuclei form and grow until they react with each other to form a new recrystalized grain structure1. Recovery: During recovery the stresses which are produced by cold work are reduced, with decrease in strength and increase in ductility. 2. Recrystallization: During recrystallization the new undeformed nuclei form and grow until they react with each other to form a new recrystalized grain structure. 3. Grain growth: The increase in grain size of new formed recrystalized grain is grain growth process. When the heated parts are quench the quenching rate at surface of metal and center of metal produce thermal gradient which will result in inhomogeneous plastic deformation

1.3. Properties and applications of 2024 Al alloy:

The 2024 aluminum alloy has high strength and high fatigue resistance. This alloy has good workability and fair machinability. But, the 2024 aluminum alloy has poor corrosion resistance and poor weldability [17].

Applications: Due to its high strength and fatigue resistance, AA 2024 is widely used in aircraft, especially wing and fuselage structures under tension, floor of air craft [18]. It is also used in the hardware, truck wheels, and parts for the transportation industry [19]. Additionally, since the material is susceptible to thermal shock, AA 2024 is used in qualification of liquid penetrant tests outside of normal temperature ranges [20].

1.4. Mechanism of Precipitation Hardening of 2024:

The precipitation hardening of aluminium 2024 is quite complex process which consist different steps or say this hardening occur in sequence of formation of different precipitates. Figure 1 shows the Aluminum copper phase diagram in which the age hardening process is shown where the process consists of basic three steps: 1)Solution Treatment: The solution treatment also called as Solutionizing, is the first step in the precipitation-hardening process. This alloy has α and θ as primary phase. When this alloy is heated above the solvus temperature and soaked the (α) is produced as the homogeneous solid solution and this θ precipitates are dissolved in this step and any segregation present in the 2024 alloy is reduced. 2) Quenching: The quenching is the second step where the homogeneous solid α is rapidly cooled by water or other liquid solution. After rapid cooling this homogeneous α make supersaturated solid solution of αSS which contains excess copper and is not an equilibrium structure. The atoms in this stage do not have time to diffuse to potential nucleation sites and thus θ precipitates do not form. 3) Aging: The aging is the third step where the supersaturated solid solution of α, is heated below the solvus temperature as shown in fig. 1 to produce a finely dispersed precipitate. Atoms diffuse only short distances at this aging temperature. In this process the supersaturated α is not stable, so the extra copper atoms is diffuse to numbers of nucleation sites and the precipitates will grow. This finely dispersed precipitate in the alloy is the objective of the precipitation-hardening process. The fine precipitates in the alloy impede dislocation movement by forcing the dislocations to either cut through the precipitated particles or go around them. By restricting dislocation movement during deformation, the alloy is strengthened [10][21].

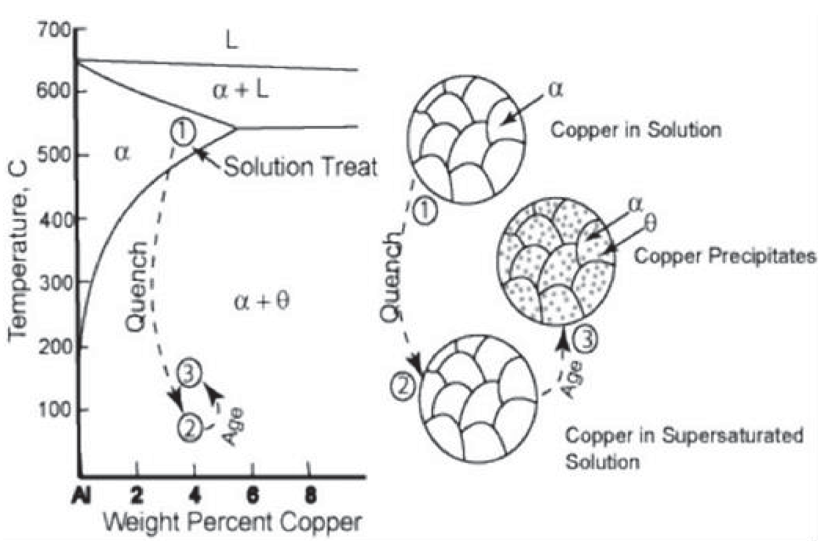

Fig. 1. Al – Cu phase diagram [22]

The age hardening process form different type of Precipitate as shown in fig. There are three type of Precipitate.

1. Coherent precipitate: The coherent precipitate is form so that there is definite relationship between the precipitates and matrix's crystal structure. This precipitates have higher hardness then other precipitates.
2. Semi coherent precipitates: This precipitates are intermediate form of coherent and incoherent type of Precipitate. This precipitates have high hardness then incoherent but lower then coherent precipitate.
3. Incoherent precipitates: This type of Precipitates does not have any relationship between precipitates and matrix crystal structure [23]

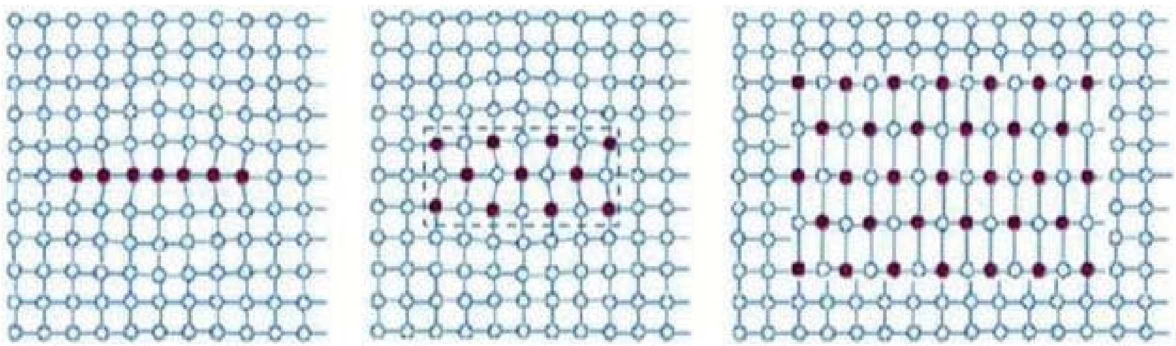

Fig. 2. Coherent, semi-coherent and incoherent precipitates [24]

The precipitation hardening process consist steps:
$a_{0\ (ssss)}$ → GP zones → θ" → → θ' → θ [23]

GP Zone: GP zone is first stage of age hardening process. This is plate like structure of copper atom which are segregated on [100] plane of aluminum lattice. They are rapidly formed after quenching that is part of clusters formed during quenching. GP zone have coherency strain. As the atomic diameter of Cu is less than Al, elastic straining is induced as a local change in inter-planer distance as shown in fig. GP zone is called coherent precipitates with straining [25].

θ" precipitates: Earlier, it was called as GP zone–2, but experiments revealed that it has definite but different crystal structure than the matrix. Θ" is coherent type precipitates. This precipitates are in plate form of minimum thickness 100 A° and up to maximum diameter of 1500 A°. This precipitates have tetragonal structure with a=0.404 nm and c=0.768 nm as shown in Figure 3. This precipitates has ordered arrangement of Cu and Al atoms. This precipitates have higher hardness then other precipitates [25].

θ' precipitates: These precipitates are large in diameter and can be observed under optical microscope. This precipitates are transition precipitates. This precipitates has tetragonal structure with a=0.404 nm and c=0.580 nm. As shown in fig. 3, the composition of θ' is differ from θ" and this precipitates are semi-coherent precipitates. The elastic strain around this precipitates is small and the formation of θ' precipitates lead to soften the alloy. So, this precipitates has lower hardness than θ" [25].

θ precipitates: This precipitates are fully incoherent precipitates. This precipitates has tetragonal structure. Formation of this precipitates always lead to soften the alloy. So, there will always lower hardness obtained in this precipitates. It nucleate heterogeneously and is more easily formed when ageing at higher temperature. This precipitates is the ultimate result of over ageing. This precipitates have tetragonal crystal structure with a=0.6066 nm and c=0.4874 nm [25].

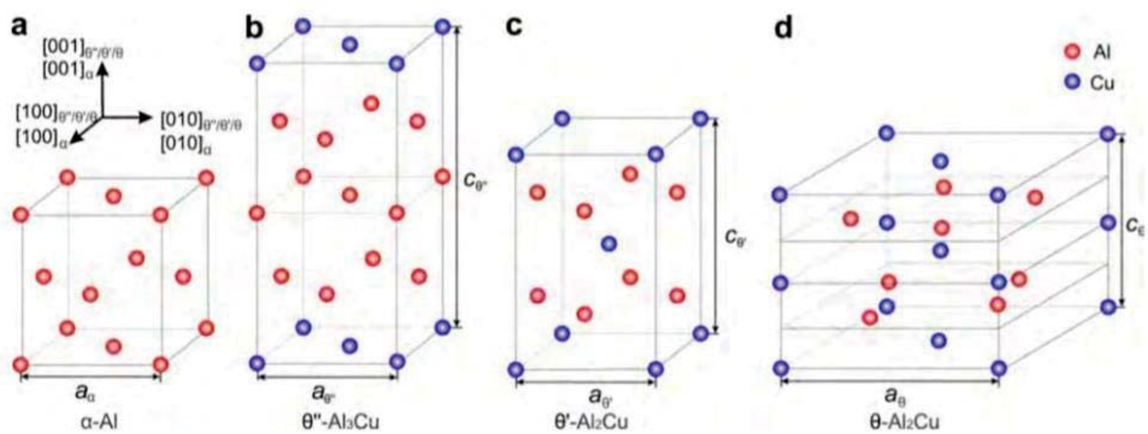

Fig. 3. Crystal structure of different precipitates [26]

The fig. 4 shows the graph of logarithm of ageing time versus strength of material which shows the strength of the sample after formation of different precipitates. As shown figure there is a peak hardness at one stage after this peak the hardness of samples decrease constantly and this is occur due to over ageing [27]. but experiments revealed that it has definite but different crystal structure than the matrix. Θ" is coherent type precipitates. This precipitates are in plate form of minimum thickness 100 A° and up to maximum diameter of 1500 A°.This precipitates has tetragonal structure. Formation of this precipitates always lead to soften the alloy.This precipitates are fully incoherent precipitates. This precipitates has tetragonal structure. Formation of this precipitates always lead to soften the alloy

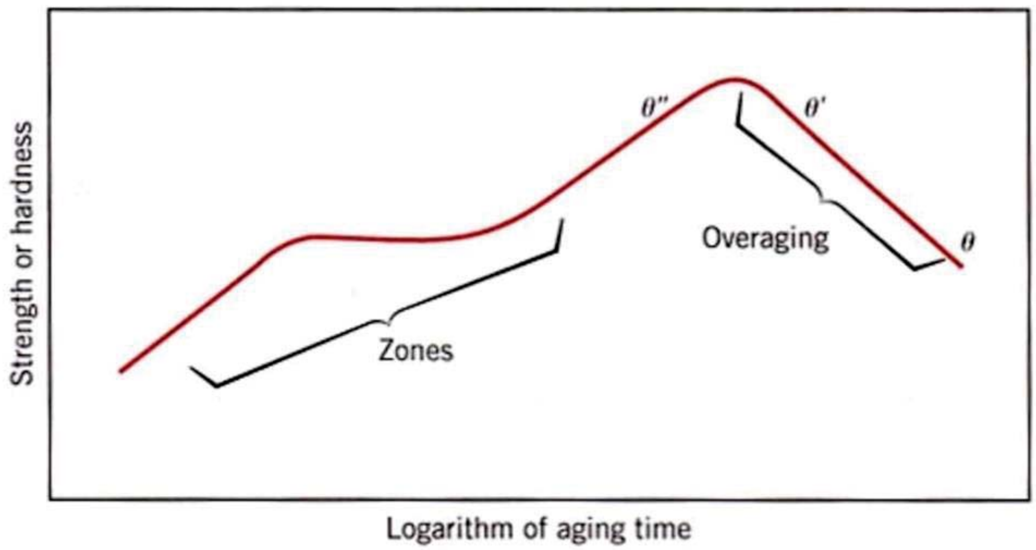

Fig. 4. Graph of strength of different precipitates [27]

1.5. Microstructure:

Fig. 5 shows the Microstructure of base metal 2024. This microstructure consist of alpha (α) and theta (θ) phase. Fig.6 shows the microstructure of annealed aluminium 2024 with different reagent like Keller's etch and week's etch. Coarse Aluminum alloy grains (~300 μm) can be observed after the solution treatment followed by quenching in water at room temperature (Fig. 7). Appearance of black spots aligned along the grain boundaries is supposed to be undissolved second phase precipitates, as also reported in [28]. Fig.8 shows the microstructure of age hardened Al 2024 which has fine alpha precipitates. This precipitates are hard in nature. These precipitates increase mechanical properties of the alloy. Smaller grains have greater ratios of surface area to volume, which means a greater ratio of grain boundary to dislocations. The more grain boundaries that exist, the higher is the strength [29].

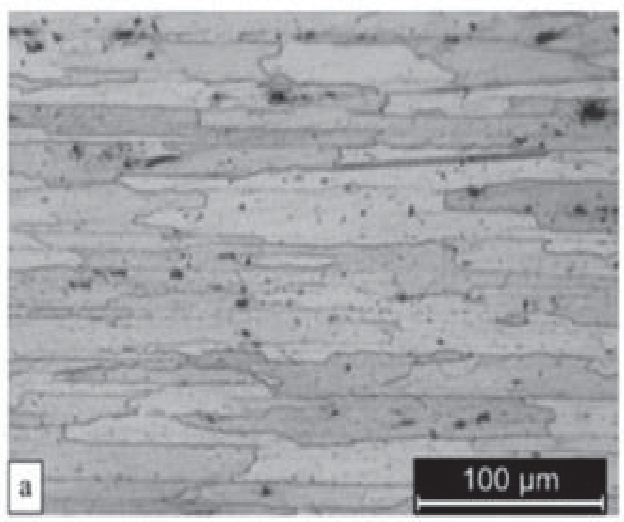

Fig. 5. Microstructure of base metal 2024 [30]

This precipitates are hard in nature. These precipitates increase mechanical properties of the alloy. Smaller grains have greater ratios of surface area to volume, which means a greater ratio of grain boundary to dislocations. Coarse Aluminum alloy grains (~300 μm) can be observed after the solution treatment followed by quenching in water at room temperature (Fig. 7). To eliminate all the residual effects that plate was subjected to the annealing process. The plate was placed in furnace at 413°C and soaked at this temperature for two hours. After this the sample was left in the furnace to cool down slowly until they had reached (250 °C) and then cooled on to room temperature.

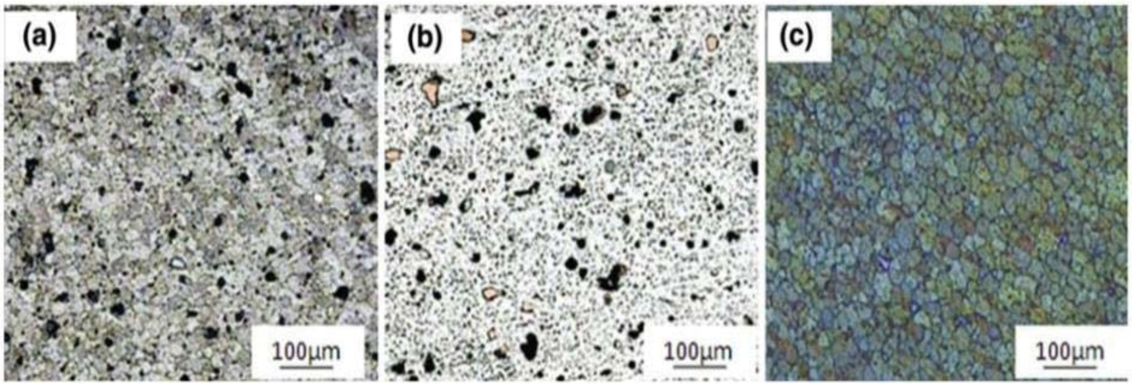

Fig. 6. Microstructures of Al 2024 – O with different reagent a Keller's etch b week's etch c new technique [31]

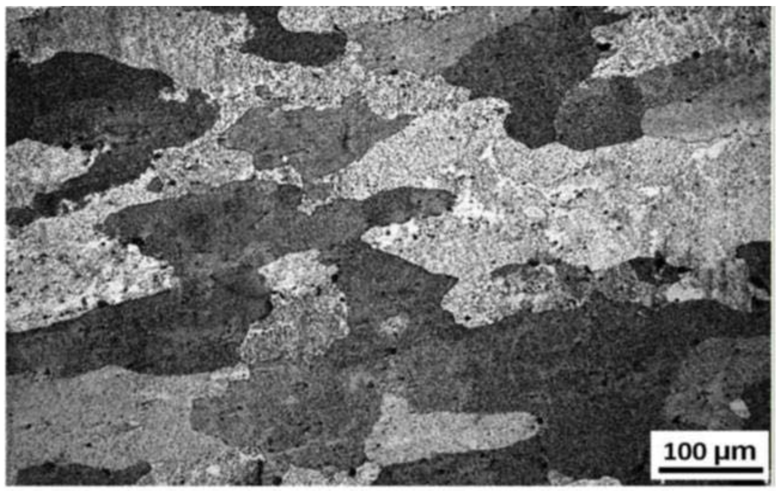

Fig. 7. Microstructures of solution treated Al 2024 [32]

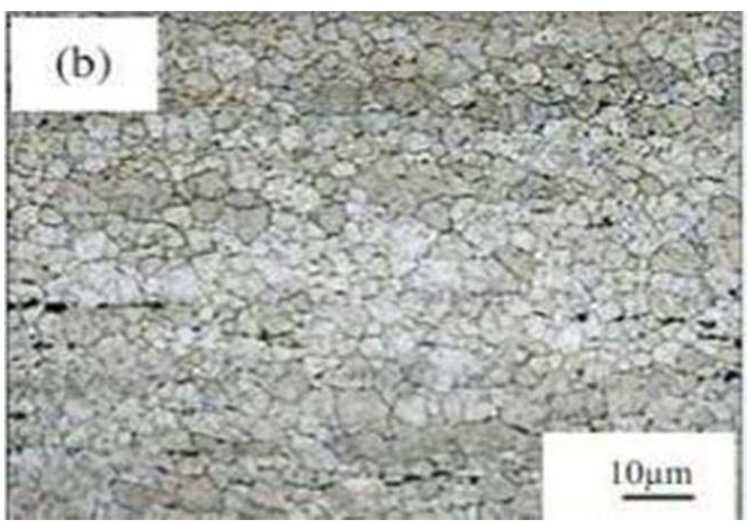

Fig. 8. Microstructure of Aluminium 2024 T6 [33]

Hussein et al [34] studied the effect of annealing, natural aging and artificial aging on properties of 2024 aluminum alloy. The study used O – Annealed, T4 – Solution heat treated and naturally aged T6 – Solution heat treated and artificially-aged alloys and the properties with water and polymeric solutions quenching medium were also studied.

Table 1. Chemical composition of 2024 [35]

Element	Al	Cu	Mg	Si	Zn	Cr	Fe	Mn	Ti	Other
% composition	90.7-94.7	3.8-4.9	1.2-1.8	0.5 max	0.25 max	0.1 max	0.5 max	0.3-0.9	0.15 max	0.05 max

To eliminate all the residual effects that plate was subjected to the annealing process. The plate was placed in furnace at 413°C and soaked at this temperature for two hours. After this the sample was left in the furnace to cool down slowly until they had reached (250 °C) and then cooled on to room temperature. Solution heat treatment was carried by performing the series of heating and cooling cycle to obtain the desired mechanical properties. This process consisted of following steps.

1. Heating to a specific temperature
2. Soaked for specific time
3. Rapid quenching in water bath
4. Age hardening

After annealing process, AA 2024-T0 was heated in the furnace up to (494°C) for about 35 minutes. At the end of this time the sample was rapidly quenched in water and returned to the furnace and heated up to (100 °C) for a period of 3 to 4 hour and cooled in room temperature. After this the specimen were cut for tensile strength and other mechanical test [34]. The mechanical and vibrational properties of AA 2024 was checked for O, T4 and T6 (annealed, naturally- aged and artificially-aged). The mechanical properties reported were as follows. The hardness of aluminium AA 2024 was measured in HRB scale at 100 kg load. The alloy obtained hardness of 101, 115, and 109 HRB for T0, T4 and T6 conditions respectively. At the same time yield strength of 150, 310, and 170 MPa, tensile strength of 340, 450 and 380 MPa, elastic modulus of 71.5, 73 and 72 GPa while % elongation of 16, 13 and 10 was obtained for T0, T4 and T6 conditions respectively [34].

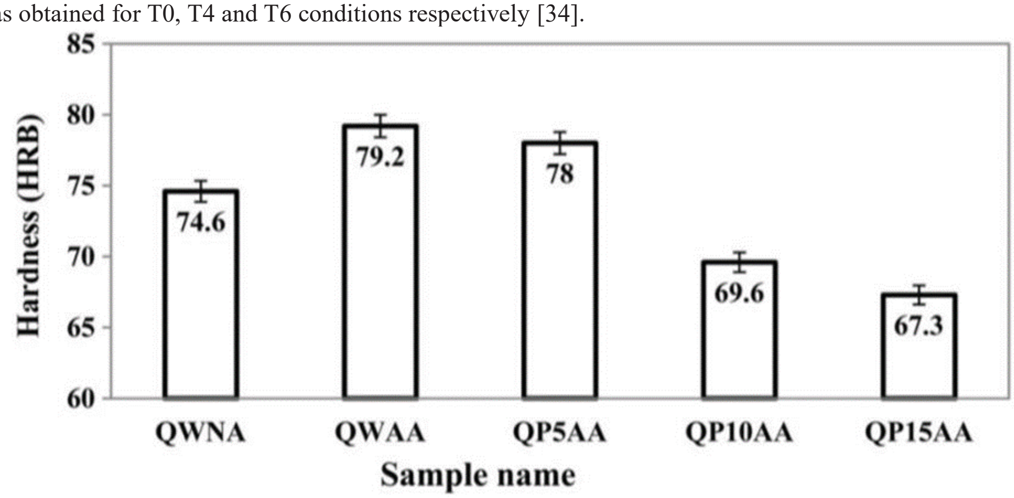

Fig. 9. Hardness of aluminum 2024 at different quenching medium [36]

The quenching medium play significant role during heat treatment. Different quenching medium can be used to get desired properties. Araghchi et. al [2] studied the effect of water quenching with natural and artificial aging and effect of different amount of polymeric solution quenching with artificial aging. Fig. 9 shows the hardness change by using different quenching mediums. QWNA is Quenching in water and natural aging, QWNA is quenching in water and mainly artificial aging, QP5AA is Quenching in 5% polymeric solution and artificial aging, QP10AA is quenching in 10% polymeric solution and artificial aging and QP15AA is quenching in 15 % polymeric solution and artificial aging. It was observed that as the percentage polymeric solution was increased, the hardness obtained decreased.

2. Summary:

From the above literature review, the effect of heat treatment like (O, T4, T6) on mechanical properties (Hardness, Yield strength, ultimate strength, modulus of elasticity and elongation) for plate 2024 can be summarized as follows:
The sample heat treated with T4 for Aluminum 2024 obtained better properties.
The mechanical properties of aluminium 2024 decreased on heat treatment with T6 condition.
Quenching medium played important role and water quenching resulted in higher hardness then polymeric solution.

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Source of Calcium – CaO & $CaCl_2$ Addition and its Recovery Effect into Pure Mg

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Abstract

Over the past few years, numbers of researchers work on the Mg-Ca system. The reason behind this area is due to its very good high specific strength and stiffness, elasticity, low density, and biocompatibility. All most, all researchers use sources of calcium in its master alloy form. The readily available master alloy contains 11 to 45 wt.% of calcium. Present research work selects two sources of calcium, like calcium oxide and calcium chloride. In both, the source of calcium, the amount of addition is fixed, and it is 3.5 wt.%. The result shows that recovery of calcium from calcium chloride is approximately 50% more compare to calcium oxide. Tensile strength, hardness, electrical conductivity, and corrosion rate measurement of developed Mg-Ca alloy were studied using the tensometer, Brinell hardness test, electrical conductivity meter, and immersion test. Results show that recovery of calcium from calcium chloride is more compare to calcium oxide. The presence of calcium increases the hardness, tensile strength, and corrosion resistance behavior. It decreases the electrical conductivity of calcium-containing alloy.

Keywords: Mg-$CaCl_2$, Mg-CaO, Tensile strength, Hardness, Corrosion rate

1. Introduction

Mg and its alloys are very useful in automotive, aircraft, electronics, and sports industries due to high strength to weight ratio, lower density, higher damping capacity, good stiffness, and easily die-cast property. [1-5] It has the potential to be used as biodegradable implants in the human body for load-bearing and bone repairing applications. However, the use of this alloy is restricted in some areas due to the highly corrosive nature of chloride and the physiological environment. By alloy addition and surface treatment, this limitation can be overcome and the corrosion rate of magnesium can be enhanced. [6-11]

Calcium plays an important role as an alloying element in pure magnesium and its alloys. It can refine the grain and improve corrosion resistance, mechanical and thermal properties, and creep resistance. As per Mg-Ca binary diagram, the solubility of calcium in magnesium is 1.34 wt. % at 516.5°C. [6,12-14] Zijian Li et. al. [14] and Yuncang Li [15] reported that a higher amount of calcium causes brittleness in Mg-Ca alloy. An ultimate strain of Mg-Ca alloy decreased with increasing calcium content. So, the ideal calcium content for magnesium alloys is less than 1 wt.% preferred. [15, 16] On the other hand, calcium addition is also effective during the melting of magnesium alloys to prevent them from ignition and oxidation. At present, ignition-proof and non-combustible Mg-Ca alloys are used in the aerospace, rail, and construction area. [16,17]

In most of the studies, to develop Mg-Ca alloy, calcium is added as Mg-Ca master alloy (Mg-20%Ca, Mg-30%Ca). [18] But, in this study calcium was added in the form of calcium oxide and calcium chloride form to check its recovery in commercially pure magnesium. The effect of Ca on the tensile strength, hardness, electrical conductivity, and corrosion rate of magnesium were examined in detail.

2. Experimental Procedure

2.1. Casting

Commercial pure magnesium ingot (97.19%), calcium oxide, and calcium chloride were used to developed Mg-Ca alloys. Pure Mg ingot and calcium sources were procured from a local supplier of Vadodara. A resistance heating furnace was used to prepare the alloy inside the inert-graphite crucible. In a molten state, magnesium has a highly oxidized nature. Thus, to protect molten Mg from oxidation and burning flux 220 was used as a cover flux. Maximum 720 °C temp. was maintained on the furnace. 3.5 wt.%

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CaO was added in molten Mg at this temperature and held for 15 minutes. After that, it was stirred and poured into a preheated metallic die after degassing defluxing. By a similar process, Mg-Ca alloy was prepared from $CaCl_2$ addition.

2.2. Compositional evaluation of prepared alloys

The compositional analysis of developed magnesium alloys was checked by EDS analysis with ± 0.01% accuracy. (JSM-5610LV). The results of developed alloys are listed in Table 1.

Table 1. Compositional analysis pure Mg and developed alloys

Pure Mg & Developed Alloys	Ca	O	Mg
Pure Mg	-	2.81	Bal.
Alloy 1: Mg-Ca alloy (CaO addition)	0.52	4.68	Bal.
Alloy 2: Mg-Ca alloy ($CaCl_2$ addition)	1.16	3.64	Bal.

2.3. Mechanical and electrical properties

Room temperature ultimate tensile strength of pure magnesium and Mg-Ca alloys were measured using Monsanto-20 machine. The cross-head speed of the machine was set at 0.05 mm/min. Dimensions of the tensile specimen are shown in fig. 1. The hardness was measured by the Brinell hardness tester at 31.25 kg load. Electrical conductivity was measured on a conductivity meter (% IACS) which is based on the eddy current principle. An average of 3 measurements was taken for all alloys.

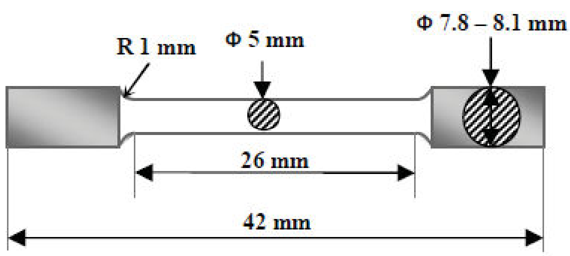

Fig. 1. Tensile Test Specimen

2.4. Immersion test

The corrosion rate of pure magnesium and both alloys was measured by immersion test (ASTM G31-71). [20] Three specimens of pure Mg and each alloy were taken. The dimensions and weight of all specimens were measured before the test. After those specimens were immersed in 3.5 weight % NaCl solution at room temperature for 24 hrs. Once the test was complete, the specimens were collected and dip in CrO_3, $AgNO_3$, Ba $(NO_3)_2$, and reagent water solution for 1 minute. [21] Specimens were dried in hot air and then weighed again.

3. Results and Discussion

3.1. Calcium recovery in magnesium

As per Haughton and Vossklihler, 1.8 % and 0.78 % Ca were soluble at 516°C respectively. [22] To develop Mg-Ca alloy, generally, Mg-Ca master alloy is added as calcium source but in this study, calcium was added in the form of calcium oxide and calcium chloride at 750 ºC. The melting point of $CaCl_2$ and CaO is around 780 ºC and 2572 ºC respectively. Due to the high melting point, calcium recovery from calcium oxide is very less i.e., 0.52 wt.%. Among both sources, maximum calcium was soluble from calcium chloride form.

3.2. Characterization of developed alloys

3.2.1 Hardness, UTS, and Electrical conductivity

Above mentioned properties are presented in fig. 2. As per result, the presence of a very small quantity of calcium increases hardness and UTS of pure Mg in a very remarkable way due to solid solution phenomena. Maximum hardness and UTS were achieved in alloy 2 - 52 BHN and 172 MPa respectively. However, the presence of calcium and Mg_2Ca precipitates obstruct the movements of electrons and decrease the electrical conductivity of pure Mg. [23]

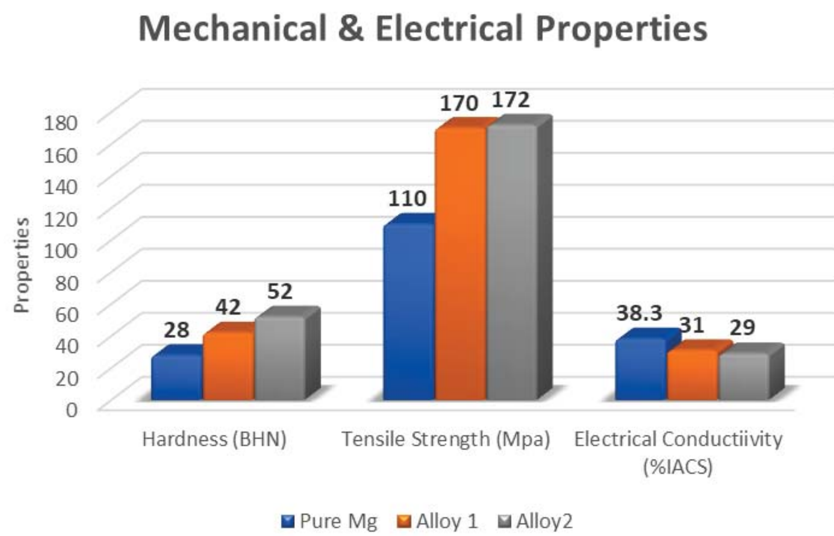

Fig. 2. Mechanical and Electrical Properties of all systems

3.3. Corrosion rate measurement

The corrosion rate of pure magnesium and developed alloys was measured by equation 1. [24]

$$mpy = \frac{534\,W}{D\,A\,T} \qquad (1)$$

To measure the density of pure magnesium and developed alloys water displacement method was used. The density of pure magnesium, Alloy 1, and alloy 2 is 1.738 gm/cc, 1.793 gm/cc, and 1.802 gm/cc respectively. Weight loss of all specimens was measured which is shown in table 2. The result shows that the corrosion rate of 0.5 wt.% calcium containing alloy is high compare to pure magnesium. However, more than 1 wt.% calcium containing alloy shows less corrosion rate compare to magnesium which shows in fig. 3.

Table 2. Weight loss in immersion test

Sr. No.	Pure Mg & Developed Alloys	Initial weight of Specimens (gm)	Final weight of Specimens (gm)	Total weight loss (gm)
1	Pure Mg	5.70	5.68	0.02
2	Alloy 1: Mg-Ca alloy (CaO addition)	5.68	5.65	0.03
3	Alloy 2: Mg-Ca alloy ($CaCl_2$ addition)	9.37	9.35	0.02

Macroscopic examination of all samples was carried out before and after the corrosion test. As shown in fig. 4 after 24 hrs. dipping in 3.5 % NaCl solution, very small pits were observed in pure magnesium sample. In Alloy 1, more pits were observed which are bigger than the pure magnesium sample. More amount of calcium decreases the corrosion rate. Here, Small and fewer pits were observed in alloy 2.

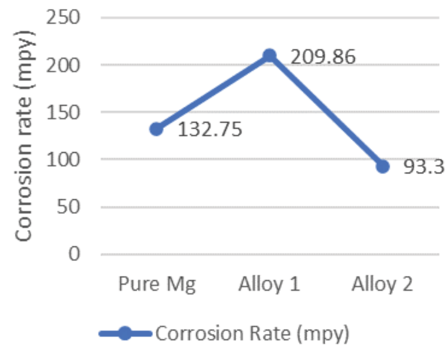

Fig.3. The corrosion rate of pure Mg and developed alloys

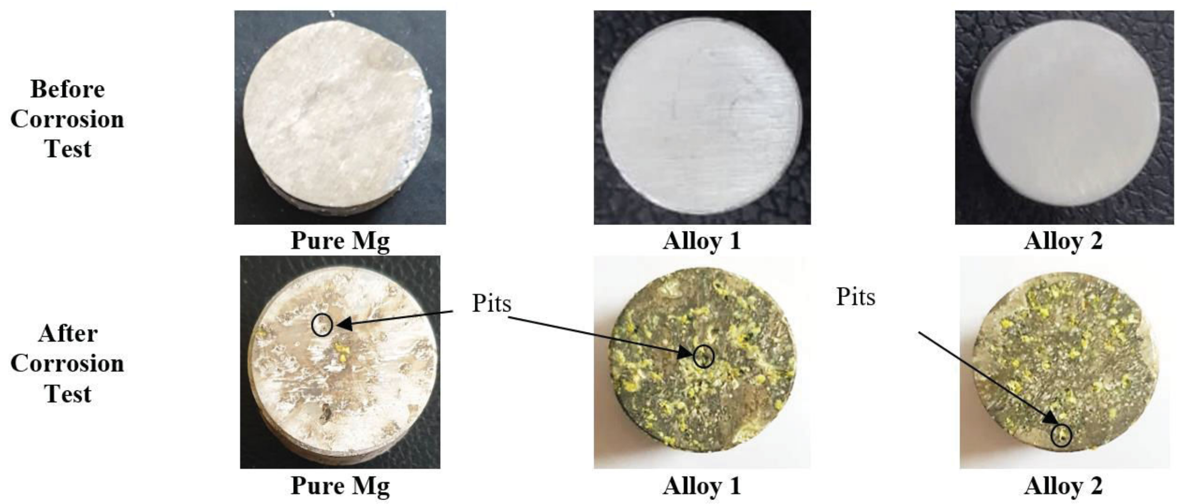

Fig.4. Sample before and after corrosion test

4. Conclusions

- Calcium chloride should also be used to develop Mg-Ca alloys. Calcium recovery from calcium chloride is more compare to calcium oxide.
- Compare to pure magnesium, the addition of 1 wt.% calcium increases hardness value from 28 BHN to 52 BHN and tensile strength from 110 MPa to 172 MPa.
- The presence of calcium in magnesium decreases electrical conductivity from 38.3 to 29 % IACS.
- The presence of calcium improves the corrosion resistance of commercially pure Mg in the case of a source of calcium from $CaCl_2$.
- In the case of the addition of calcium oxide, instead of reducing the corrosion rate, it accelerates it compare to commercially pure magnesium.
- Compare to the source of CaO and $CaCl_2$, $CaCl_2$ addition offers higher hardness, tensile strength, and even corrosion resistance value.

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